NUCLEAR WEAPONS COLLATERAL DAMAGE EXAGGERATIONS: IMPLICATIONS FOR CIVIL DEFENSE

Nigel Cook

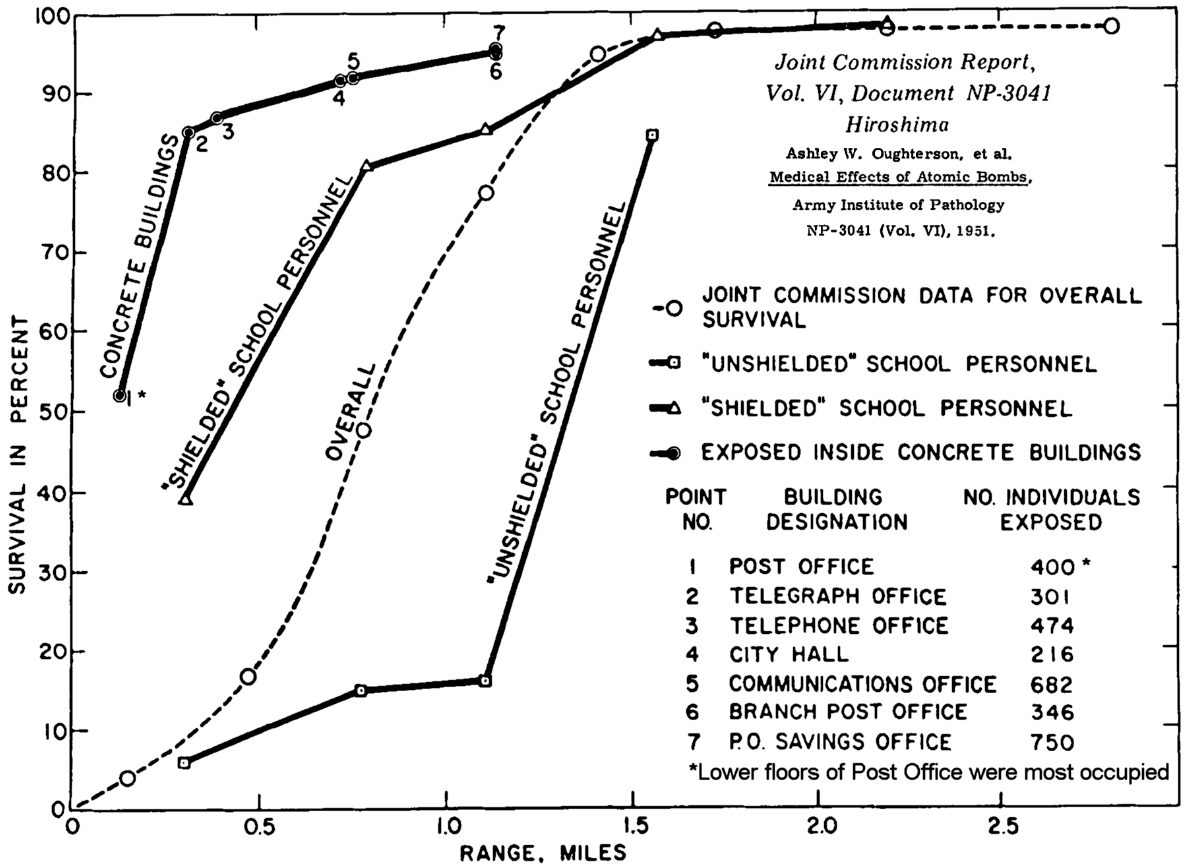


Figure 1: Dr Ashley W. Oughterson and other members of the Joint Commission for the Investigation of the Effects of the Atomic Bomb in Japan in 1951 produced a six volume report called *Medical Effects of Atomic Bombs* (U. S. Office of the Air Surgeon, and U. S. Army Institute of Pathology), summarizing research done into case histories for personnel in known locations in the open and within buildings at the time of the August 1945 nuclear explosions in Hiroshima and Nagasaki. Volume VI (document NP-3041) contained the data shown above, proving the immense increase in survival due to protective actions against easily-shielded thermal and nuclear radiation. This data is vital for civil defense but is not being applied to the analysis of casualty rates from nuclear explosions for civil defense, since propaganda from America and Japan instead presents an "average" casualty curve, which covers up and obfuscates the differences in survival rates in different situations. In particular, the curves above disprove the "uniformly lethal firestorm" myth. Blast survivors were not all killed in the firestorm.

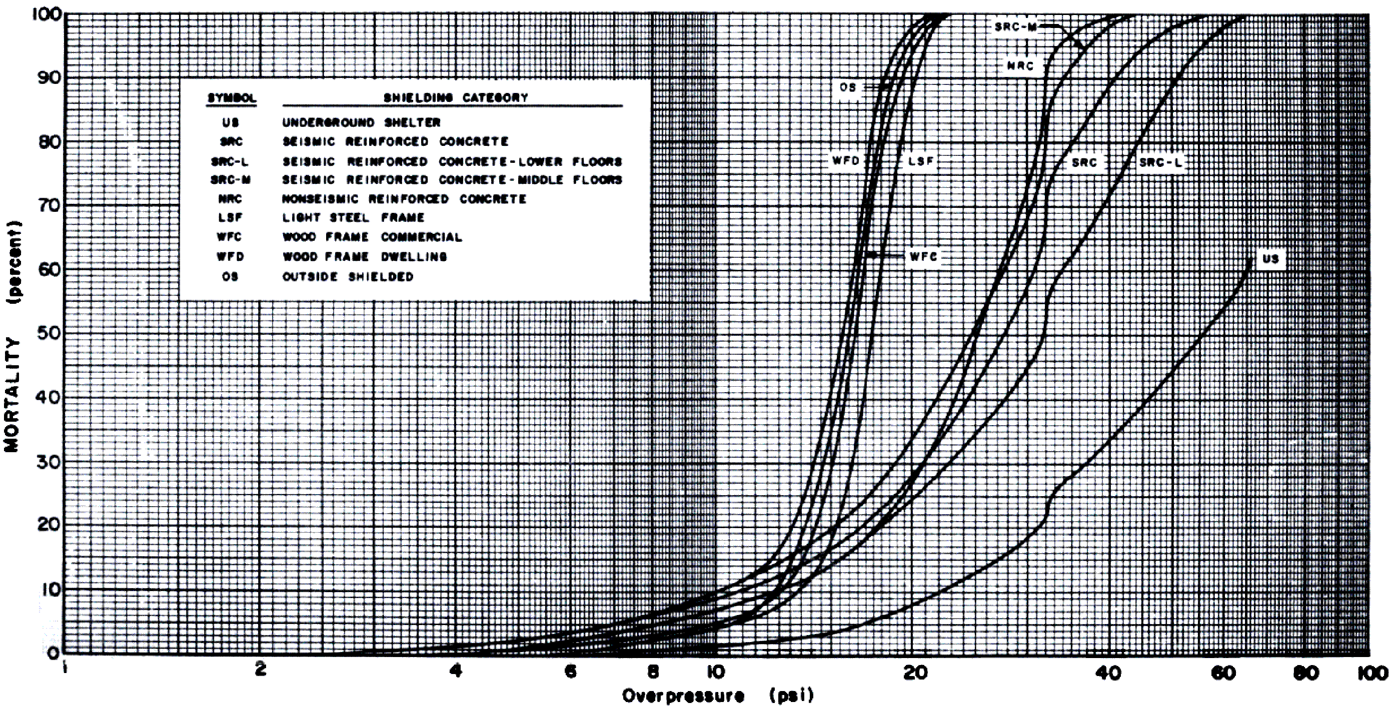
The Effects of the Atomic Bomb on Hiroshima, Japan, Report No. 92 (Vols. I-III), U.S. Strategic Bombing Survey, Physical Damage Division; May, 1947.

Effects of the Atomic Bomb on Nagasaki, Japan, Report No. 93 (Vols. I-III), U.S. Strategic Bombing Survey, Physical Damage Division; June, 1947.

Figure 2: The U. S. Strategic Bombing Survey classified its detailed reports 92 and 93 on the nuclear explosions in Hiroshima and Nagasaki "Secret", and instead published an obfuscating summary report which omits the evidence that the firestorm in Hiroshima was due to the overturning of charcoal cooking braziers in bamboo and paper screen filled wooden houses, not thermal radiation. This caused anti-civil defense propaganda to falsely associate the firestorm radius to the thermal radiation exposure at that radius, instead of correctly associating it to the blast effect in overturning obsolete charcoal braziers. Report 92 on Hiroshima actually states (pages 4-6, May 1947): "Six persons who had been in reinforced-concrete buildings within 3,200 feet [975 m] of air zero [i.e., $(975^2 - 600^2)^{1/2}$ = 770 m ground range] stated that black cotton black-out curtains were ignited by flash heat... A large proportion of over 1,000 persons questioned was, however, in agreement that a great majority of the original fires were started by debris falling on kitchen charcoal fires...."

The unclassified 1957 U. S. Department of Defense book *The Effects of Nuclear Weapons* obfuscated this evidence, vaguely stating on pages 322-3: “Definite evidence was obtained from Japanese observers that the thermal radiation caused thin, dark cotton cloth, such as the black-out curtains that were in common use during the war, thin paper, and dry, rotted wood to catch fire at distances up to 3,500 feet (0.66 mile) from ground zero (about 35 calories per square centimetre).” Thus, black coloured curtails, thin paper and dry, rotted wood, needed 35 cal/cm^2 to ignite in the coastal cities of Japan during August when there was high humidity. White curtains, which are more common now that air raid precautions no longer demand black window curtains, require much higher thermal exposures for ignition than black curtains.

TOTAL MORTALITY CURVES FOR NAGASAKI



TOTAL MORTALITY CURVES FOR HIROSHIMA

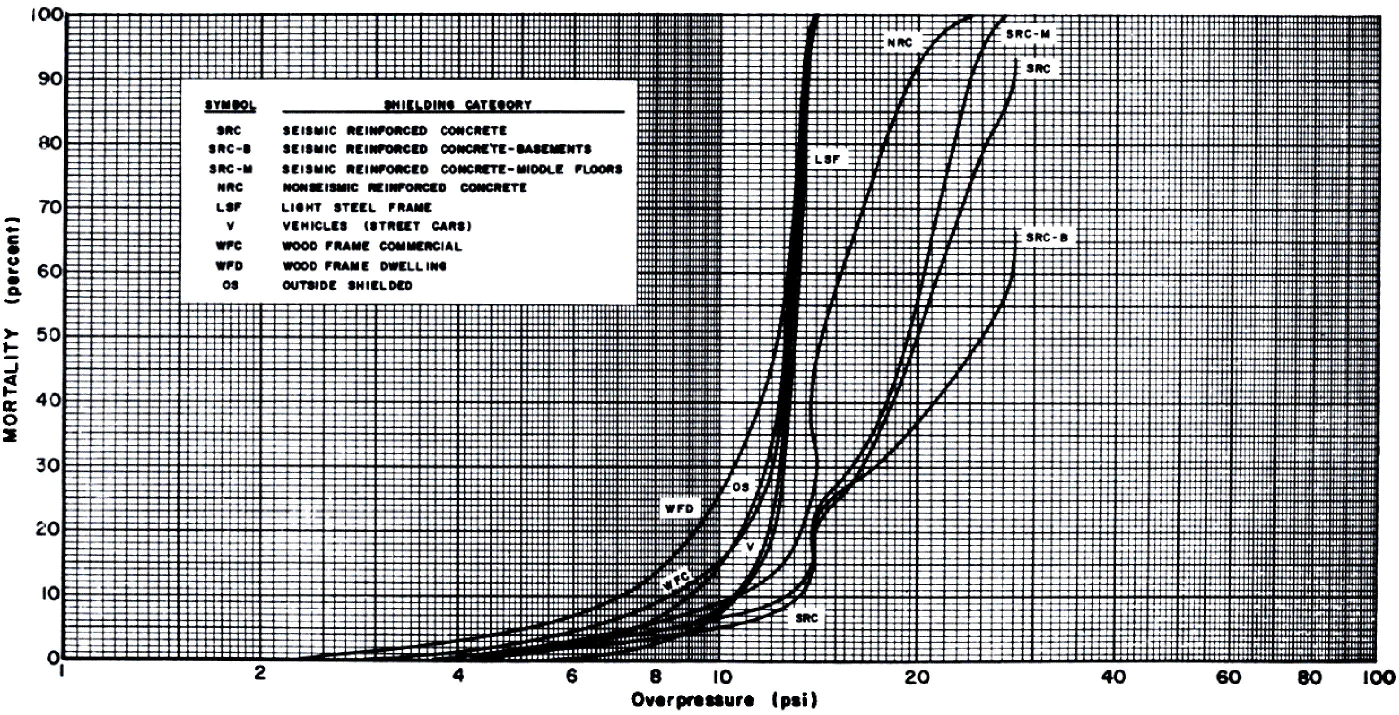


Figure 3: The Peak overpressures for casualties from all effects of nuclear explosions. Source: L. Wayne Davis, *Prediction of Urban Casualties and the Medical Load from a High-Yield Nuclear Burst,* Dirkwood Corporation paper DC-P-1060-1 (1968). The data assumes a yield of 22 kt for Nagasaki (close to 21 kt used in DS02) and 12.5 kt for Hiroshima (lower than 16 kt used for DS02). Correcting the yields increases the overpressures for observed mortality, reconciling much low peak overpressure data for both cities. Small differences occur due to different neutron radiation outputs and the firestorm in Hiroshima.

Peak overpressures for casualties from all effects of nuclear explosions. Source: L. Wayne Davis, *Prediction of Urban Casualties and the Medical Load from a High-Yield Nuclear Burst,* Dirkwood Corporation paper DC-P-1060-1 (1968)

Explosion	Building type	10% killed	50% killed	90% killed
Nagasaki (22 kt nuclear air burst over city, 1945). Below 16 psi peak overpressure, the lower floors of buildings were subjected to the horizontal Mach stem blast wave, while above 16 psi buildings were subject to regular reflection (downward, radial incident blast, then the ground-reflected blast wave).	Wood-frame	10 psi	15.6 psi	18 psi
	Outside but in thermal flash shadow (no burn)	12.5 psi	16 psi	19 psi
	Light steel frame	13 psi	17.5 psi	20 psi
	Seismic reinforced concrete, lower floors	12.5 psi	32 psi	51 psi
	Underground shelters	22 psi	55 psi	N/A
Texas City Disaster (0.67 kt non-nuclear explosion in Texas City, 1947). Peak overpressures for given casualties are higher than at Nagasaki, because of the lack of initial nuclear radiation; although fires were ignited by hot debris from an exploding ship.	Wood-frame	9.0 psi	22.5 psi	30 psi
	Light steel frame	13 psi	30.6 psi	46 psi
	Outside but in thermal flash shadow (no burn)	11 psi	26.5 psi	46 psi
	Heavy steel frame and non-seismic reinforced concrete	11-14 psi	40 psi	70 psi
Hiroshima (16 kt nuclear air burst over city, 1945). Peak overpressures are underestimates based on 12.5 kt (rather than 16 kt) yield; a firestorm contributed to the fatalities shown, because some people were trapped in fires.	Wood-frame	7.0 psi	12.2 psi	13.5 psi
	Outside but in thermal flash shadow (no burn)	9.0 psi	13 psi	13.5 psi
	Light steel frame	10.5 psi	13 psi	13.5 psi

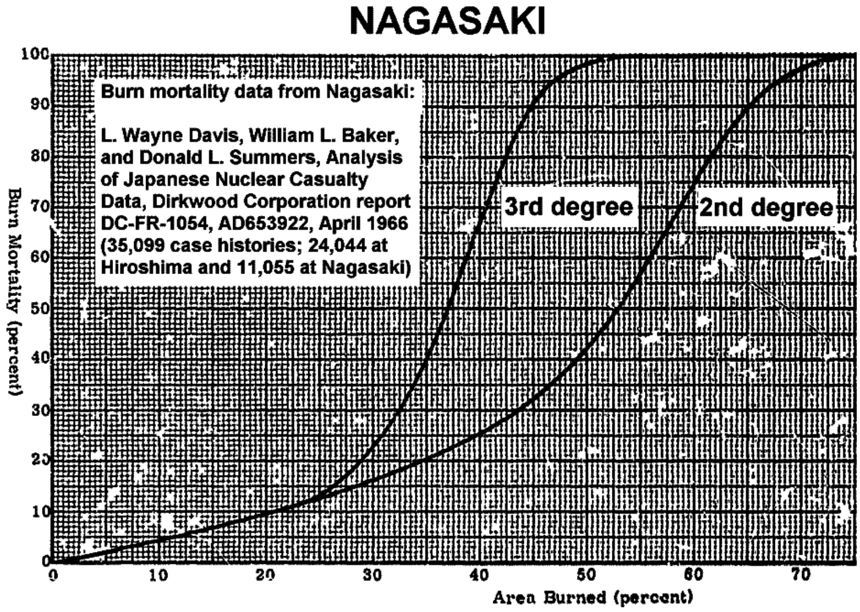
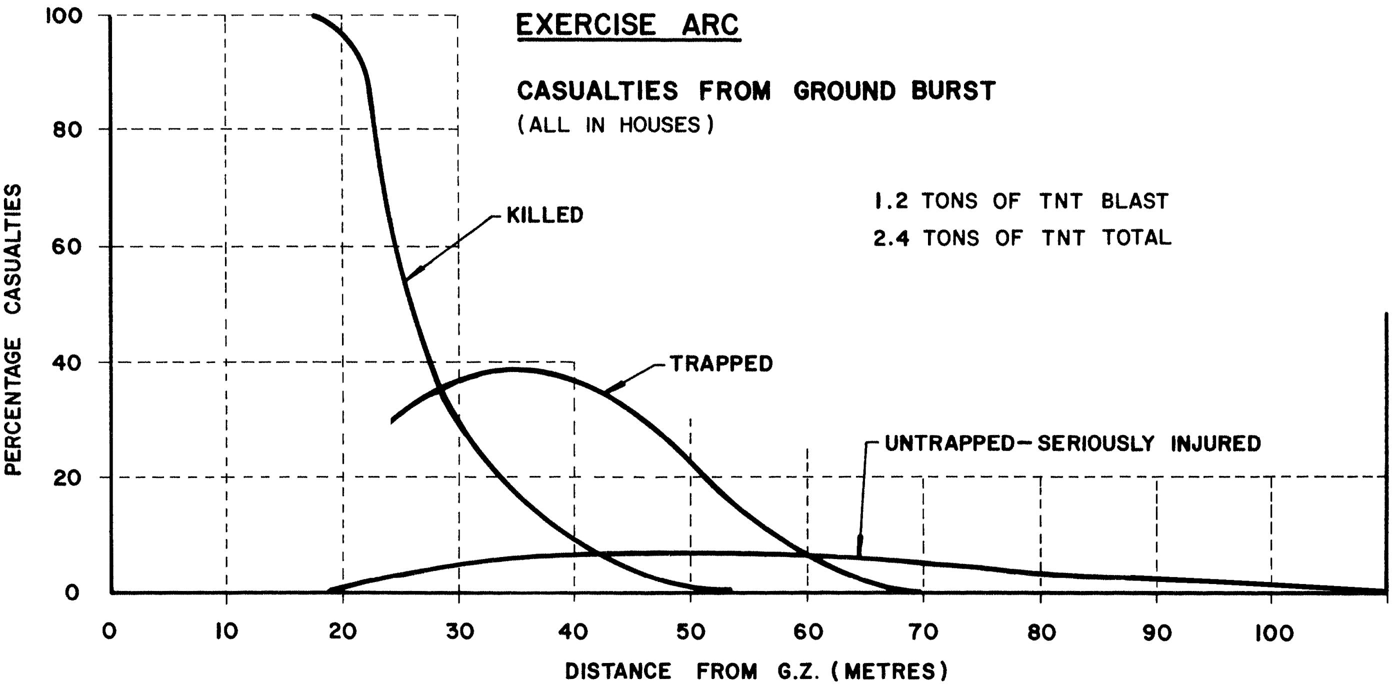


Figure 4: The Dirkwood Corporation report *Analysis of Japanese Casualty Data,* DC-FR-1054, AD653922 (1966), gives the basic survival data for 35,099 case histories of personnel exposed to nuclear explosions over cities in Japan, August 1945 (24,044 at Hiroshima and 11,055 at Nagasaki). This graph shows the effects mortality to outdoor personnel in terms of the percentage of body area (easily derived from the "rule of nines") subjected to thermal blistering (2nd degree) and surface charring (3rd degree) burns. Contrary to popular propaganda, the mortality depended on the body area burned, since shadows from clothing, buildings, trees, fences, vehicles, people, and terrain provided substantial protection against thermal radiation.

In Hiroshima, the Dirkwood data (DC-FR-1054, Fig. 34) shows that the distance from ground zero for 50% survival ranged from 140 metres for the lower floors of earthquake-standard concrete buildings to 730 metres for vehicles (street cars/trolley buses/trams) and 880 metres for wood-frame dwellings. Outdoors, casualty rates depended essentially on thermal radiation exposure in combination with initial nuclear radiation (which suppressed the white blood cell count during burn healing, allowing fatal infections in many cases), and its shadowing by clothing, trees, buildings, fences, terrain, vehicles, etc., rather than blast. People outdoors in thermal shadows were not burned and survived high peak overpressures like those in buildings, as shown. Most people outdoors moved out of shadows into a clear radial line of sight to watch the B-29 aircraft and saw the bomb fall, unaware of the danger, and were flash-burned in silence before the blast wave arrived and knocked them down. Mortality for people outdoors without thermal shielding was 10% for 12 cal/cm^2, 50% for 16 cal/cm^2, and 90% for 18 cal/cm^2 (these figures apply to the light summer clothing worn in August and include enhancements due to synergism of burns with initial nuclear radiation).

At 3.05 km ground range in Nagasaki, 43% had 2nd degree burns (blistering) and 5% had 3rd degree burns (charring), although even light clothing offered complete protection here, so the body area burned was small and recovery was possible in all cases. There was no significant nuclear radiation at that distance to accompany the thermal flash burns and delay or prevent recovery from the burns. At 1.86 km ground range in Nagasaki, there was 10% mortality to persons outdoors without thermal shadowing, due to the 53% of cases having 3rd degree burns and 36% having 2nd degree burns, an average total body burned area of 20% (DC-FR-1054, Figs. 28 and 29). A rate of 50% mortality for unshielded persons outside in Nagasaki occurred at 1.37 km from ground zero, where 72% of cases had 3rd degree and 18% had 2nd degree burns, with an average total body burned area of 38%. The reason for the increase in area from 20% average area burned at 1.86 km (10% killed) to 38% average area burned at 1.37 km (50% killed) in Nagasaki was simply that the burns were more likely to occur under light summer clothing as the thermal radiation increased. At low thermal exposures, a low protection factor by clothing is sufficient to stop any burns under clothing.



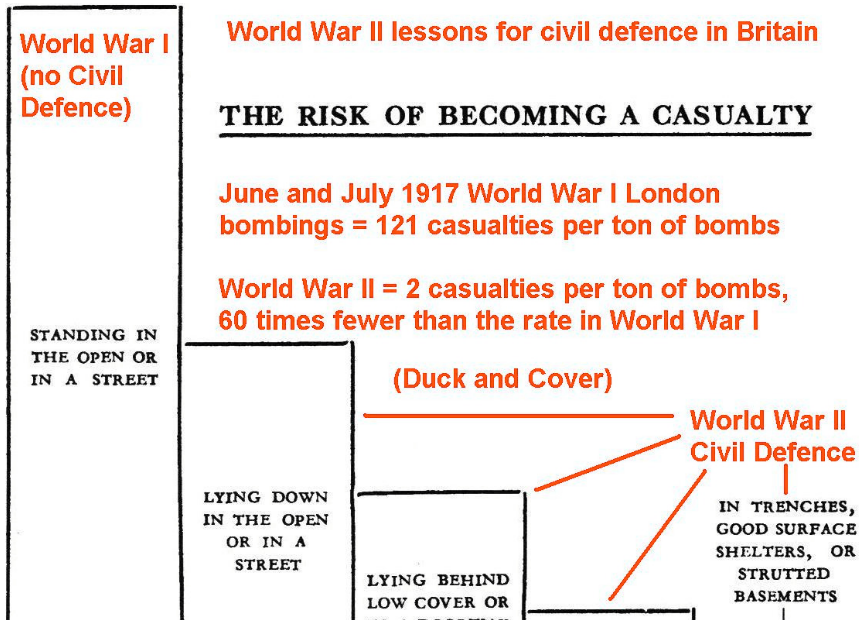


Figure 5: The value of duck and cover as protection against hurricane force blast winds and flying debris was proved in Britain during the Blitz bombing. The blast casualty rates to unprotected personnel in cities during bombing in World War I was reduced by simple countermeasures during World War II. Sources: U. K. Home Office publications, "Exercise Arc" (1959), "History of the Second World War: Civil Defence" (Terrence O' Brien for H. M. Stationery Office, 1955), and "Basic Methods of Protection Against High Explosive Missiles" (1949). (1.2 tons of TNT ≡ 2.4 tons nuclear yield for 50% blast.)

~~CONFIDENTIAL~~

DEPARTMENT OF THE ARMY TECHNICAL MANUAL — TM 23-200
DEPARTMENT OF THE NAVY — OPNAV INSTRUCTION 03400.1B
DEPARTMENT OF THE AIR FORCE — AFL 136-1
MARINE CORPS PUBLICATIONS — NAVMC 1104 REV

CAPABILITIES OF ATOMIC WEAPONS (U)

Prepared by
Armed Forces Special Weapons Project

DEPARTMENTS OF THE ARMY, THE NAVY
AND THE AIR FORCE

REVISED EDITION NOVEMBER 1957

~~CONFIDENTIAL~~

FIGURE 5-2 ~~CONFIDENTIAL~~

	1 KT	100 KT (cal/cm²)	10 MT
Thermal effects:			
Second degree bare skin burn	4	5. 1	9. 1
Army khaki summer uniform destruction	18	31	56
Navy white uniform destruction	34	60	109
Blast effects (in the Mach region):			
Severe damage to overpressure sensitive structures:		(PSI overpressure)	
Blast-resistant designed buildings	50	40	35
Reinforced concrete buildings	10. 5	9. 5	9
Monumental wall bearing buildings	20	15	15
Wood frame housing	3	3	3
Window pane breakage	0. 5	0. 5	0. 5
Severe damage to dynamic pressure sensitive structures:		(PSI dynamic pressure)	
Light steel frame single story buildings	4. 5	2	0. 9
Heavy steel frame single story buildings	6	3	1. 5
Steel frame multistory buildings	7. 5	2. 5	0. 9
150′–250′ span truss bridges	50	8	5. 5

5–12 ~~CONFIDENTIAL~~

~~CONFIDENTIAL~~ 6.1c (3)

Table 6–1. Estimated Casualty Production in Structures for Various Degrees of Structural Damage

	Killed outright	Serious injury (hospitalization)	Light injury (No hospitalization)
1–2 story brick homes (high explosive data):	Percent	Percent	Percent
Severe damage	25	20	10
Moderate damage	<5	10	5
Light damage	------	<5	<5
Reinforced-concrete buildings (Japanese data, nuclear):			
Severe damage	100	------	------
Moderate damage	10	15	20
Light damage	<5	<5	15

Note. These percentages do not include the casualties which may result from fires, asphyxiation, and other causes from failure to extricate trapped personnel. The numbers represent the estimated percentage of casualties expected at the maximum range where the specified structural damage occurs.

6.2 Thermal Injury

a. Introduction. Before attempting to predict the number of thermal casualties which occur in a given situation, it is necessary to recognize the factors which influence the number and distribution of casualties to be expected. These factors include—the distribution or deployment of personnel within the target area, whether proceeding along a road, in foxholes, standing or prone, in the open or under natural cover; orientation with respect to the bomb; clothing, including number of layers, color, weight, and whether the uniform includes helmets, gloves, or other devices which might protect the bare skin, such as flash creams; and natural shielding.

~~CONFIDENTIAL~~ 6–3

6.2b ~~CONFIDENTIAL~~

b. Primary Radiant Energy Burns. Damage to bare skin through the production of burns may be directly related to the radiant exposure and the rate of delivery of the thermal radiation, both of which are yield dependent. For a given total exposure, as the weapon yield increases, the thermal radiation is delivered over a longer period of time and thus at a lower rate. This allows energy loss from the skin surface by conduction to the deeper layers of the skin and by convection to the air.

c. Burns Under Clothing. Clothing reflects and absorbs much of the thermal radiation incident upon it and thereby protects the wearer against flashburn. In some cases, the protection is complete, but in many cases it is partial in that clothing merely reduces the severity of injury rather than preventing it. At large radiant exposures, there is the additional possibility that the glowing or ignition of the clothing could deliver additional energy to the skin, thereby causing a more severe injury than bare skin would have suffered.

Table 6–2. Critical Radiant Exposures for Burns Under Clothing

(Expressed in cal/cm² incident on outer surface of cloth)

Clothing	Burn	1 KT	100 KT	10 MT
Summer Uniform	1°	8	11	14
(2 layers)	2°	20	25	35
Winter Uniform	1°	60	80	100
(4 layers)	2°	70	90	120

Note. These values are sensitively dependent upon many variables which are not easily defined (see text), and are probably correct within a factor of two.

6–4 ~~CONFIDENTIAL~~

Figure 6: WWII blast and thermal casualty data was classified Confidential in TM 23-200, *Capabilities of Atomic Weapons*.

The Effects of Atomic Weapons

PREPARED FOR AND IN COOPERATION WITH THE U. S. DEPARTMENT OF DEFENSE AND THE U. S. ATOMIC ENERGY COMMISSION

Under the direction of the

LOS ALAMOS SCIENTIFIC LABORATORY

Los Alamos, New Mexico

Revised September 1950

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PRINCIPLES OF AN ATOMIC EXPLOSION

A. INTRODUCTION

Characteristics of an Atomic Explosion

1.1 The atomic bomb is a new weapon of great destructive power. It resembles bombs of the more conventional type in so far as its explosive effect is the result of the very rapid liberation of a large quantity of energy in a relatively small space. But it differs from other bombs in three important respects: first, the amount of energy released by an atomic bomb is a thousand or more times as great as that produced by the most powerful TNT bombs; second, the explosion of the bomb is accompanied by highly-penetrating, and deleterious, invisible rays, in addition to intense heat and light; and third, the substances which remain after the explosion are radioactive, emitting radiations capable of producing harmful consequences in living organisms. It is on account of these differences that the effects of the atomic bomb require special consideration.

1.2 A knowledge and understanding of the mechanical and radiation phenomena associated with an atomic explosion are of vital importance. The information may be utilized, on the one hand, by architects and engineers in the design of structures; while on the other hand, those responsible for civil defense, including treatment of the injured, can make preparations to deal with the emergencies that may arise from an atomic explosion.

1.3 During World War II many large cities in England, Germany, and Japan were subjected to terrific attacks by high-explosive and incendiary bombs. Yet, when proper steps had been taken for the protection of the civilian population and for the restoration of services after the bombing, there was little, if any, evidence of panic. It is the purpose of this book to state the facts concerning the atomic bomb, and to make an objective, scientific analysis of these facts. It is hoped that as a result, although it may not be feasible completely to allay fear, it will at least be possible to avoid panic.

[1] Material contributed by G. Gamow, S. Glasstone, J. O. Hirschfelder.

8.91 From measurements made at the time of the Bikini "Baker" test, it has been possible to draw some general conclusions with regard to the integrated or total radiation dosage received at various distances from surface zero.

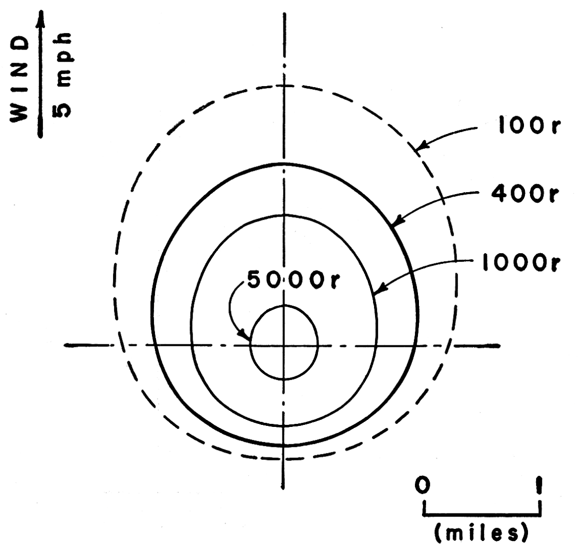

Figure 8.91a. Contours for various integrated radiation dosages due to base surge from underwater burst.

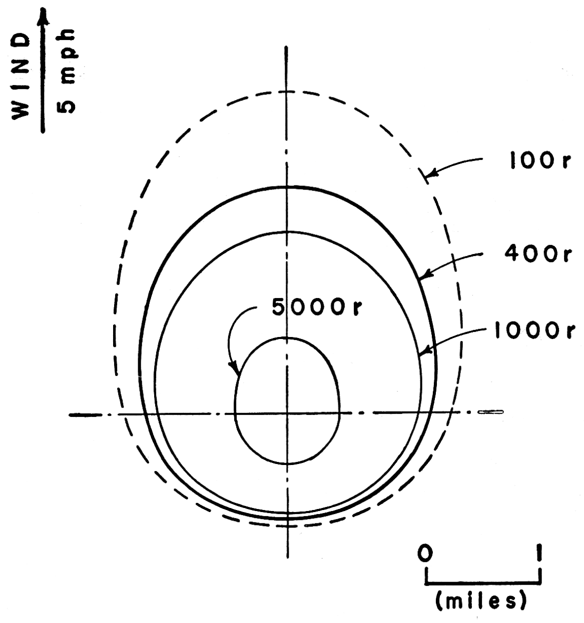

Figure 8.91b. Contours for various integrated radiation dosages due to contamination from underwater burst.

Figure 7: During *Operation Crossroads* on 25 July 1946 an underwater nuclear explosion occurred, *Baker* (23.5 kt at 90 feet depth in 180 feet of water within Bikini Lagoon, Pacific). The mushroom cloud consisted of small sea-water droplets. After about 12 seconds the "column" or stem of the mushroom rapidly collapsed to form a radioactive wind-carried surface "base surge" mist, and rapidly spread out, enveloping and irradiating ships nearby. Then the water droplets in the mushroom cloud head fell back in a "rainout" which reached the surface about one minute after detonation, contaminating the ships. The wind affected both the base surge and the cloud rainout. In 1950 the dose patterns from each phenomenon were published (above).

The Effects of

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SAMUEL GLASSTONE
Editor

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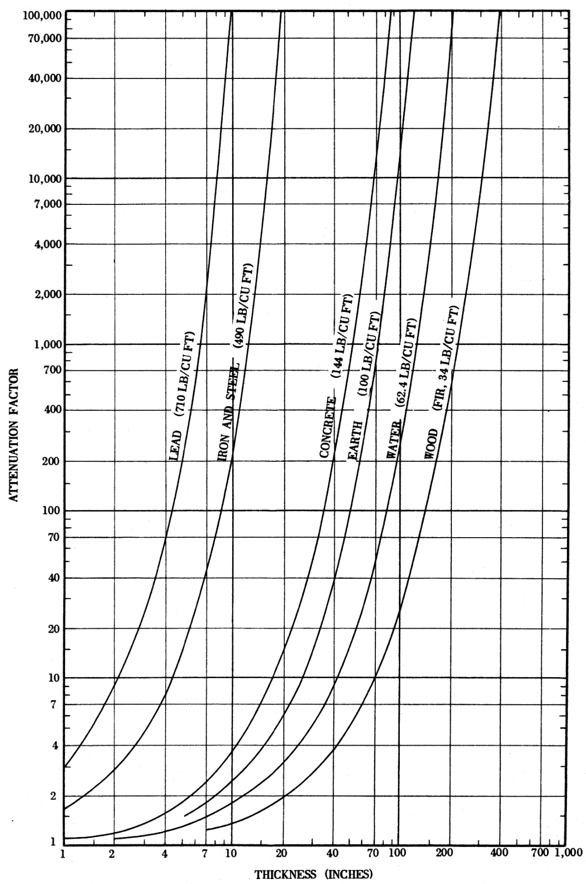

Figure 8.47. Attenuation of initial gamma radiation.

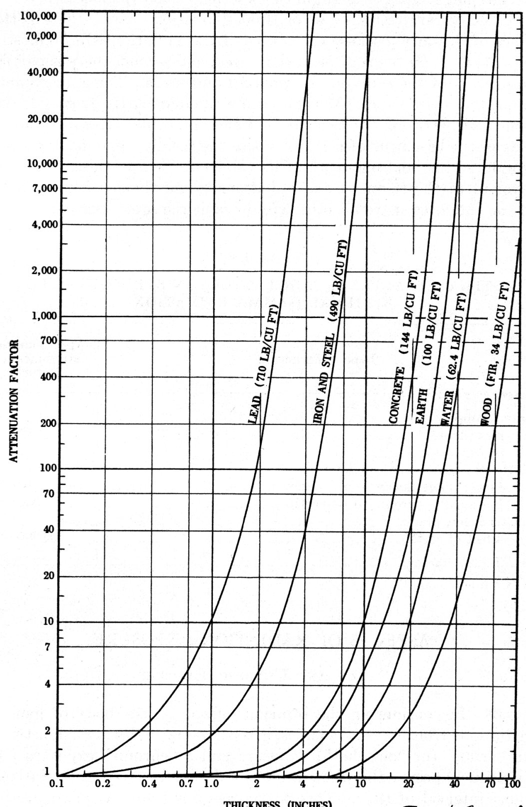

Figure 9.36. Attenuation of fission product radiation. (FALLOUT)

12.60 In the event of a surprise attack, when there is no opportunity to take shelter, immediate action could mean the difference between life and death. The first indication of an unexpected nuclear explosion would be a sudden increase of the general illumination. It would then be imperative to avoid the instinctive tendency to look at the source of light, but rather to do everything possible to cover all exposed parts of the body. A person inside a building should immediately fall prone and crawl behind or beneath a table or desk. This will provide a partial shield against splintered glass and other flying missiles. No attempt should be made to get up until the blast wave has passed, as indicated possibly by the breaking of glass, cracking of plaster, and other signs of destruction. The sound of the explosion also signifies the arrival of the blast wave.

12.61 A person caught in the open by the sudden brightness due to a nuclear explosion, should drop to the ground while curling up to shade the bare arms, hands, neck, and face with the clothed body. Although this action may have little effect against gamma rays and neutrons, it might possibly help in reducing flash burns due to thermal radiation. The degree of protection provided will vary with the energy yield of the explosion. As stated in § 7.53, it is only with high-yield weapons that evasive action against thermal radiation is likely to be feasible. Nevertheless, there is nothing to be lost, and perhaps much to be gained, by taking such action. The curled-up position should be held until the blast wave has passed.

12.62 If shelter of some kind, no matter how minor, e. g., in a doorway, behind a tree, or in a ditch, or trench can be reached within a second, it might be possible to avoid a significant part of the initial nuclear radiation, as well as the thermal radiation. But shielding from nuclear radiation requires a considerable thickness of material and this may not be available in the open. By dropping to the ground, some advantage may be secured from the shielding provided by the terrain and surrounding objects. However, since the nuclear radiation continues to reach the earth from the atomic cloud as it rises, the protection will be only partial. Further, as a result of scattering, the radiations will come from all directions.

Figure 8: Data on gamma radiation shielding and civil defence against fires was published in *The Effects of Nuclear Weapons.*

The Effects of

Nuclear Weapons

SAMUEL GLASSTONE
Editor

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Foreword

This book is a revision of "The Effects of Nuclear Weapons" which was issued in 1957. It was prepared by the Defense Atomic Support Agency of the Department of Defense in coordination with other cognizant governmental agencies and was published by the U.S. Atomic Energy Commission. Although the complex nature of nuclear weapons effects does not always allow exact evaluation, the conclusions reached herein represent the combined judgment of a number of the most competent scientists working on the problem.

There is a need for widespread public understanding of the best information available on the effects of nuclear weapons. The purpose of this book is to present as accurately as possible, within the limits of national security, a comprehensive summary of this information.

Secretary of Defense

Chairman
Atomic Energy Commission

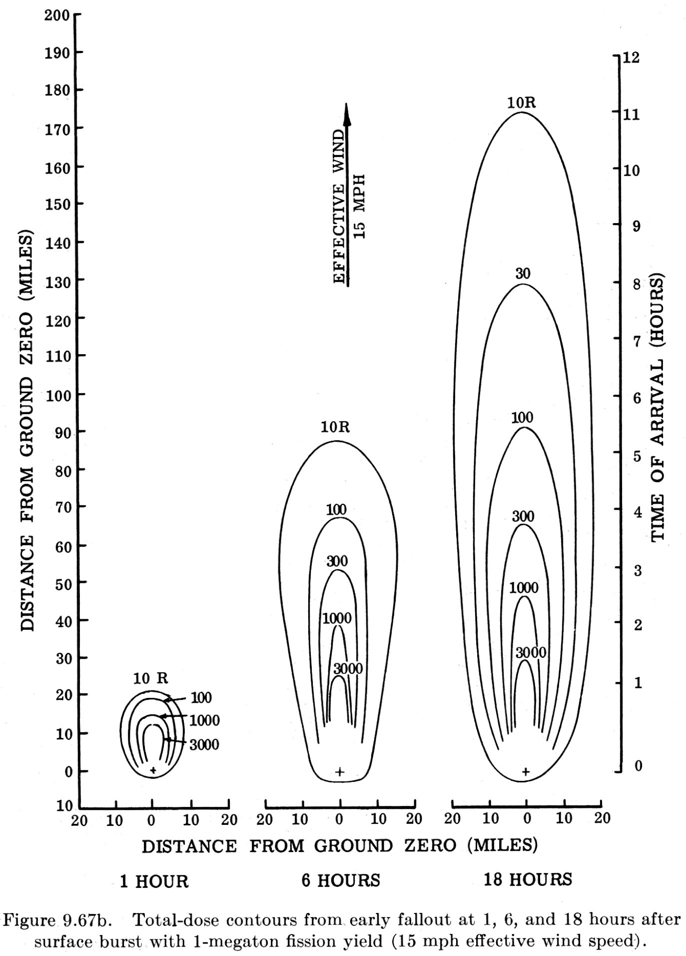


Figure 9.67b. Total-dose contours from early fallout at 1, 6, and 18 hours after surface burst with 1-megaton fission yield (15 mph effective wind speed).

12.78 In the event that shelters are not available, certain evasive actions may prove helpful at distances where the immediate effects are least severe. By instantly falling prone and covering exposed portions of the body or getting behind opaque objects, much of the thermal radiation may be avoided, especially in the case of large-yield weapons. Under no circumstances should an individual look in the direction of the fireball. Staying behind thick walls or lying in a deep ditch may help to avoid initial nuclear radiation. All of the above actions will also help to decrease the possible danger from the blast wave. Moreover, persons should avoid areas which have frangible materials, such as window glass, plaster, etc., which may become flying debris by the action of the blast.

12.79 After the immediate effects of the nuclear explosion are over, certain acts are required to minimize the hazards of the early fallout and from the fires which may result from thermal radiation and secondary blast effects. First, if small fires can be quickly extinguished, extensive conflagrations may be prevented. This must be accomplished before the arrival of the fallout or in areas of low radioactivity levels. Some protection from the fallout may be secured in the basements of buildings or in a quickly constructed shelter, such as is described in § 12.55. It is important to keep from coming into physical contact with the fallout particles, and to prevent contamination of food and water sources. Monitoring equipment should be used to determine areas which have safe radiation levels and decontamination efforts can proceed to recover necessary equipment, buildings, and areas.

CONCLUSION

12.80 Much of the discussion presented in earlier sections of this chapter have been based, for simplicity, on the effects of a single weapon. It must not be overlooked that in a nuclear attack some areas may be subjected to several bursts. The basic principles of protection would remain unchanged, but protective action against *all* the effects of a nuclear explosion—blast, thermal radiation, initial nuclear radiation, and fallout—would become even more important.

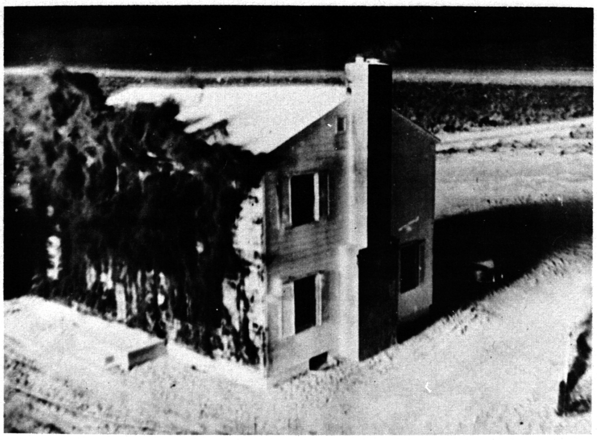


Figure 7.33a. Thermal effects on wood-frame house 1 second after explosion (about 25 cal/sq cm).

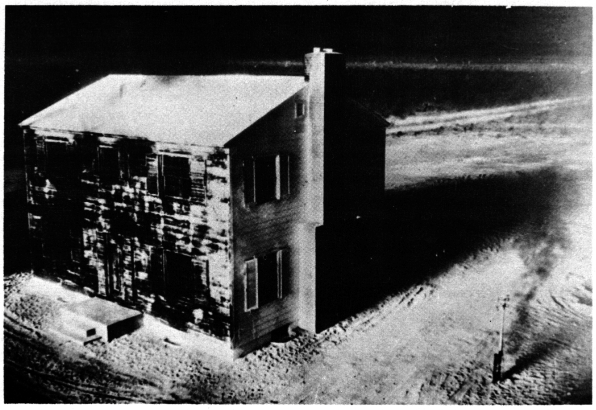


Figure 7.33b. Thermal effects on wood-frame house about ¾ second later.

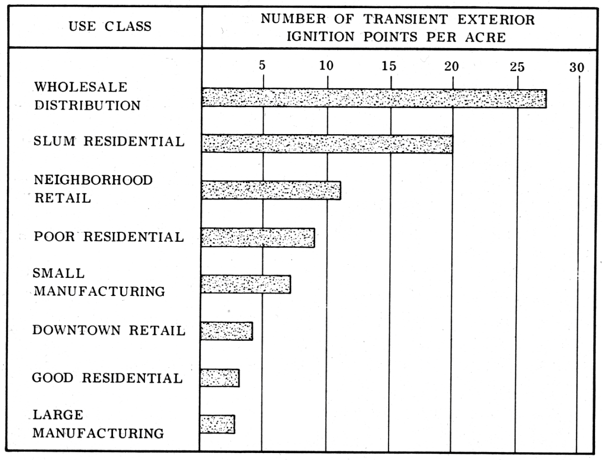


Figure 7.55. Frequency of exterior ignition points for various areas in a city

the formation of a significant fire, capable of spreading, will require appreciable quantities of combustible material close by, and this may not always be available.

7.57 The fact that accumulations of ignitable trash close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses, each having a yard enclosed with a wooden fence, were exposed to 12 calories per square centimeter of thermal radiation. One house, at the left of Fig. 7.57, had weathered siding showing considerable decay, but the yard was free from trash. The next house also had a clean yard and in addition, the exterior siding was well maintained and painted. In the third house, at the right of the photograph, the siding, which was poorly maintained, was weathered, and the yard was littered with trash.

7.58 The state of the three houses after the explosion is seen in Fig. 7.58. The third house, at the right, soon burst into flame and was burned to the ground. The first house, on the left, did ignite but it did not burst into flame for 15 minutes. The well maintained house in the center with the clean yard suffered scorching only. It is of interest to recall that the wood of a newly erected white-painted

Figure 7.57. Wooden test houses before exposure to a nuclear explosion, Nevada Test Site.

Figure 7.58. Wooden test houses after exposure to a nuclear explosion.

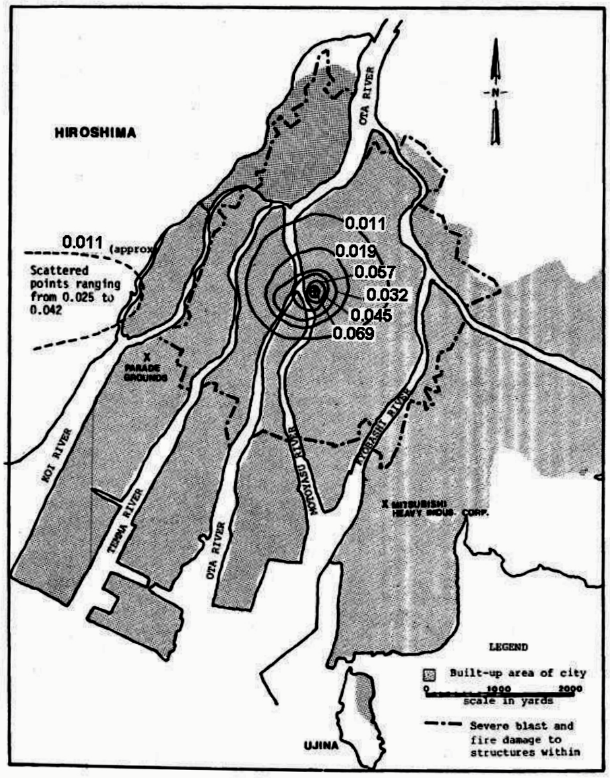
house exposed to about 25 calories per square centimeter was badly charred but did not ignite (see Fig. 7.33b).

7.59 The value of fire-resistive furnishing in decreasing the number of ignition points was also demonstrated in the tests. Two identical, sturdily constructed houses, each having a window 4 feet by 6 feet facing the point of burst, were erected where the thermal radiation exposure was 17 calories per square centimeter. One of the houses contained rayon drapery, cotton rugs, and clothing, and, as was expected, it burst into flame immediately after the explosion and burned completely. In the other house, the draperies were of vinyl plastic, and rugs and clothing were made of wool. Although much ignition occurred, the recovery party, entering an hour after the explosion, was able to extinguish the fires.

7.60 There is another point in connection with the initiation of fires by thermal radiation that needs consideration. This is the possibility that the flame resulting from the ignition of a combustible material may be subsequently extinguished by the blast wind. It was thought that there was evidence for such an effect from an observation made in Japan (§ 7.67), but this may have been an exceptional case. The matter has been studied, both in connection with the effects in Japan and at various nuclear tests, and the general conclusion is that the blast wind has no significant effect in extinguishing fires (§ 7.68).

SPREAD OF FIRES

7.61 The spread of fires in a city, including the development of a "fire storm" to which reference is made in § 7.75, depends upon a variety of conditions, e.g., weather, terrain, and closeness and combustibility of the buildings. Information concerning the growth and spread of fires from a large number of ignition points, such as might follow a nuclear explosion, and their coalescence into large fires (or conflagrations) is limited to the experience of World War II incendiary raids and the two atomic bomb attacks. There is consequently some uncertainty concerning the validity of extrapolating from these limited experiences to the behavior to be expected in other cities. It appears, however, that if other circumstances are more-or-less the same, an important criterion of the probability of fire spread is the distance between buildings. It is evident, from general considerations, that the lower the building density or "built-upness" of an area, the less will be the probability that fire will spread from one structure to another. Furthermore, the larger the spaces between buildings the greater the chances that the fire can be extinguished.



Results of the Naval Medical Research Institute (NMRI) survey performed in Hiroshima on November 1-2, 1945, showing residual radiation levels of 0.069 milliroentgen per hour (mR/hr) in the vicinity of ground zero and 0.011 mR/hr at the outermost contour. Source: DNA 5512F.

The NMRI survey report (Measurement of the Residual Radiation Intensity at the Hiroshima and Nagasaki Atomic Bomb Sites, NMRI-160A) documents a residual exposure rate of 0.081 mR/hr at the hypocenter, as well as spot measurements of 0 and 9 mR/hr among the "scattered points" to the west of the city center. These values are not represented on the map in DNA 5512F.

Figure 9: Residual radioactivity due to fallout and neutron induced activity in Hiroshima was collected in detailed surveys during 1945 that were kept secret. Hiroshima and Nagasaki have been continuously occupied! The two 16-21 kt air bursts at about 600 metres over the cities produced no significant local fallout.

DNA EM-1
PART I

DEFENSE NUCLEAR AGENCY EFFECTS MANUAL NUMBER 1

CAPABILITIES OF NUCLEAR WEAPONS

1 JULY 1972

HEADQUARTERS
Defense Nuclear Agency
Washington, D.C. 20305

Problem 5-12. Calculation of Fallout Gamma Radiation Dose Rate Contours for Bursts in the Transition Zone

[redacted] Figure 5-43 may be used to determine whether or not a burst is in the transition zone, i.e., below a height of burst of $100W^{0.35}$ feet. Burst heights below the curve in Figure 5-43 are in the transition zone. Burst heights above the curve are air bursts. In some situations, it may be desirable to consider bursts below $180W^{0.4}$ feet to be in the transition zone for conservative estimates. The means for doing this are discussed below. When a burst occurs in the transition zone, an approximation of the resulting fallout contamination patterns may be obtained by multiplying the dose rate contour values for a contact surface burst weapon of the same yield by an adjustment factor from Figure 5-44. The curves of Figure 5-44 were constructed under the assumption that the ratio of the dose rate values from a burst in the transition zone to the dose rate values for the same contour from a surface burst are proportional to the ratio of the volume of a segment of a sphere intercepted by the ground surface to the volume of the hemisphere, where the radius of the sphere is $100W^{0.35}$ feet, i.e.,

$$\text{Adjustment Factor} = \frac{\left(100 - \frac{h}{W^{0.35}}\right)^2 \left(200 + \frac{h}{W^{0.35}}\right)}{2 \times 10^6},$$

where h is the actual height of burst in feet, and W is the total weapon yield in kilotons.

[redacted] In view of the lack of data from bursts in the transition zone over a land surface, a more conservative estimate may be desired. In this case, the height of burst for the upper limit of the transition zone is taken to be $180W^{0.4}$ feet. The adjustment factor to be applied to dose rate values for the same contours from a surface burst of the same yield can be calculated from:

$$\text{Adjustment Factor} = \frac{\left(180 - \frac{h}{W^{0.4}}\right)^2 \left(360 + \frac{h}{W^{0.4}}\right)}{1.17 \times 10^7}.$$

[redacted] *Example* [redacted]

Given: A hypothetical weapon with a total yield of 600 kt, of which 200 kt results from fission, is burst 560 feet over a land surface with 10 knot effective wind conditions.

Find: The contour parameters for a dose rate of 15 rads/hr at $H + 1$ hour reference time over smooth terrain.

Solution: From Figure 5-43, a 600 kt weapon burst below about 940 feet would be in the transition zone. A height of burst of 560 feet is less than three quarters of the limiting altitude of the transition, so fallout is the only residual radiation to be considered. The 15 rads/hr contour for a fission yield to total yield ratio of 200/600 = 1/3 corresponds to the contour for 15 ÷ 1/3 = 45 rads/hr for a weapon of 600 kt fission yield. The dose rate over reasonably level terrain is about 70 percent of that over an ideal smooth plane. Thus, the ideal smooth plane contour parameters for this weapon burst on the surface would correspond to

$$\frac{45}{0.7} = 64 \text{ rads/hr}.$$

From Figure 5-44 (or from the normal adjustment factor equation given above) the height of burst adjustment factor for a 600 kt weapon burst at 560 feet is 0.21. Therefore, the desired contour parameters can be obtained by entering Figures 5-28, 5-31, 5-34, and 5-37 with a yield of 600 kt and reading the parameter values corresponding to an $H + 1$ hour dose rate of

$$\frac{64}{0.21} = 300 \text{ rads/hr}.$$

5-97

Figure 10: By the time cloud stem debris is carried into the fireballs of air bursts, the fission products and weapon residue have long since condensed into solid particles within a toroidal shaped vortex. Incoming dust enters the hole in the ring and up over the top, cascading back without mixing with the condensed fission products, so no significant local fallout is formed.

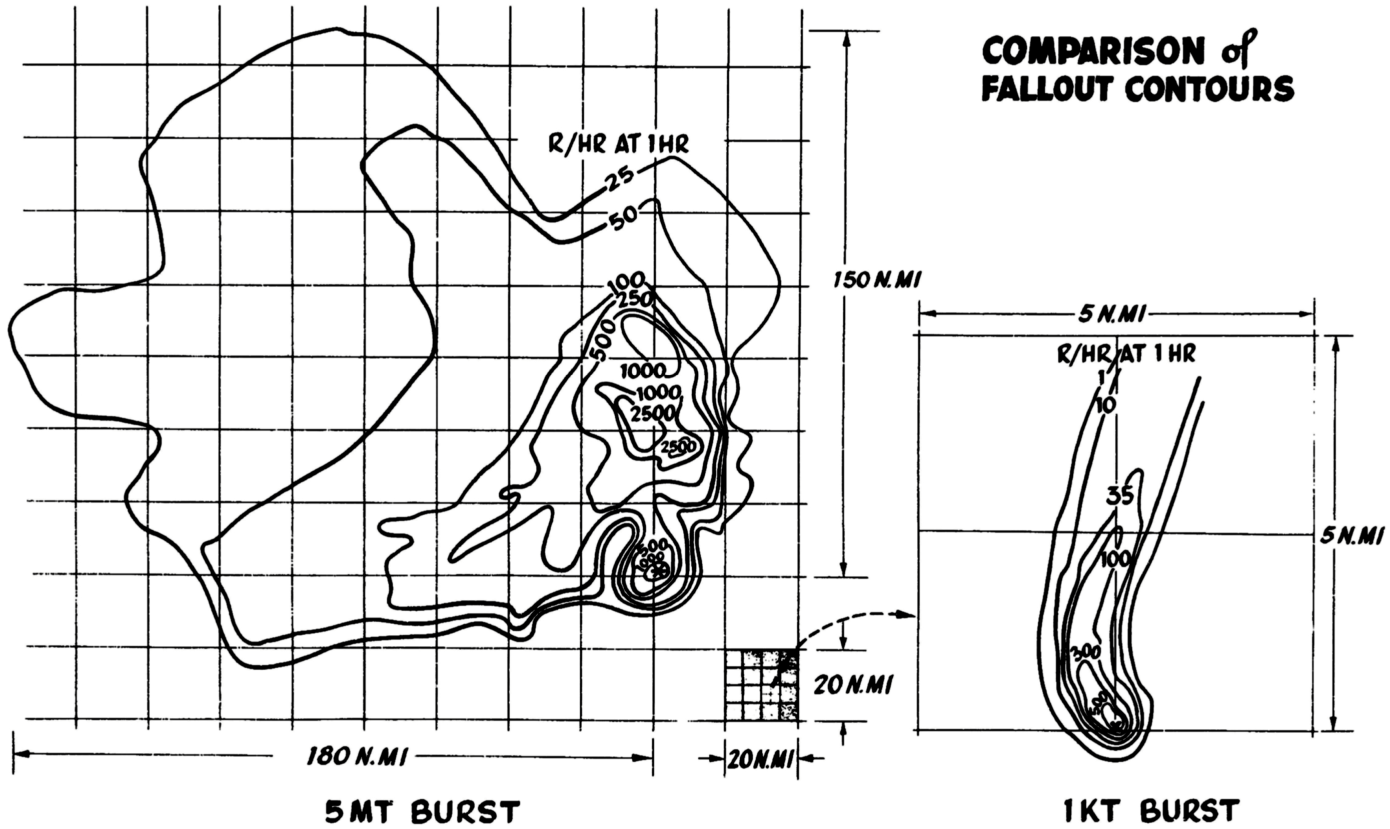


Figure 11: Pacific 5 Mt 87% fission surface burst *Redwing-Tewa* (1956) and Nevada 1.2 kt 100% fission surface burst *Jangle-Sugar* (1951), from Dr Terry Triffet's testimony to the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, U. S. Congress, *Biological and Environmental Effects of Nuclear War,* hearings on 22-26 June 1959. Failures in fallout predictions at both Nevada and Pacific tests were due to the fact that the shots had to occur under unstable wind conditions, since the prevailing winds in both cases blew towards the east (towards inhabited St George and Rongelap Atoll).

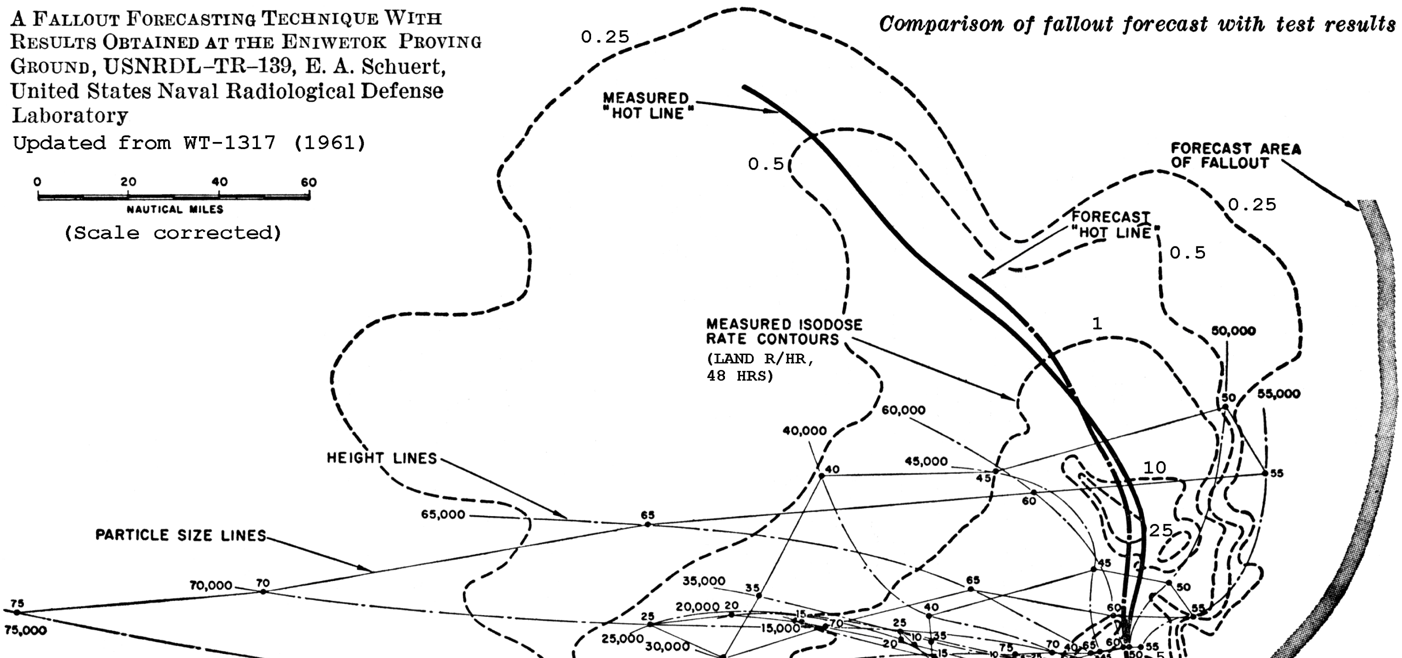


Figure 12: The accurate *Redwing-Tewa* (1956) fallout prediction of the hotline and high-intensity areas were made using a hand fallout forecasting technique by Edward A. Schuert aboard ship under simulated combat conditions. Schuert explained why fallout prediction was hard in his report *A Fallout Forecasting Technique with Results Obtained at the Eniwetok Proving Ground* (USNRDL-TR-139, 1957): "proper firing conditions, which required winds that would deposit the fallout north of the proving ground, occurred only during an unstable synoptic situation of rather short duration."

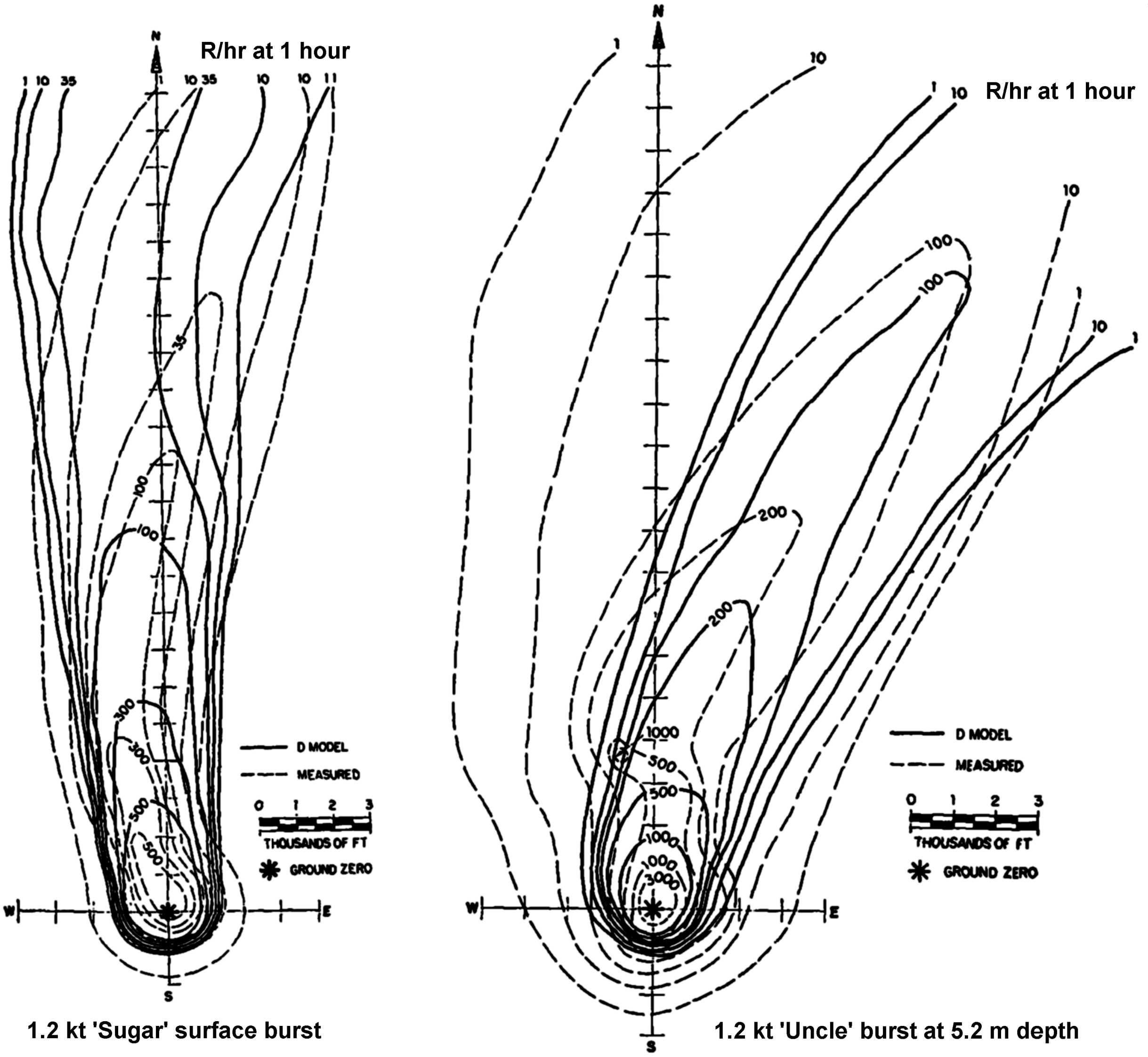


Figure 13: Dr Albert D. Anderson's U. S. Naval Radiological Defense Laboratory computerized "Dynamic Fallout Model" in 1959 reproduced the *Jangle-Sugar* (1951) fallout pattern with sufficient accuracy for civil defense using only shot-time winds (*The NRDL Dynamic Model for Fallout from Land-Surface Nuclear Bursts,* USNRDL-TR-410). At the June 1959 U. S. Special Subcommittee on Radiation hearings, *Biological and Environmental Effects of Nuclear War,* the fallout research project officer for *Redwing,* Dr Terry Triffet, testified (p. 110) that wind shear and instability (variations over short intervals of time) were characteristic of the Pacific testing area: "... the winds over the Eniwetok Proving Grounds have a tendency to vary more than the winds over the United States ..." Charles K. Shafer later testified (p. 208): "... Dr Triffet showed yesterday ... a multimegaton detonation [*Redwing-Tewa*] in the Pacific in which there was a tremendous fanning out of the fallout ... We do not have that type of wind behavior in the United States except possibly in the Gulf States in the summertime ...".

This Dynamic fallout model was the precursor to DELFIC, the U. S. Department of Defense's Land Fallout Interpretative Code, and it included some of the key features. The "Dynamic" in its name is due to its analysis of fallout from the time of creation, through the sweep-up process in the mushroom stem updraft, to deposition: "Large particles reach their maximum altitude and are falling while smaller particles are still rising."

In the *Jangle-Sugar* test fallout pattern there was little wind shear at the cloud altitude, and the mean vector wind velocity from thr ground to the cloud top was 40 km/hour. The maximum dose rate from fallout (outside of crater) was 540 R/hr at 1 hour, which occurred 900 feet downwind. Dose rates of 500, 300, and 100 R/hr occurred 2,200, 4,900, and 12,500 feet downwind at 1 hour after detonation. The *Jangle-Uncle* test was a similar 1.2 kt device detonated 5.2 metres underground in Nevada soil, where the mean vector wind velocity was 20 km/hour. The surface wind was only 3.2 km/hour, which allowed the ground level "base surge" to carry radioactivity a considerable distance upwind (a factor which Anderson did not include in his fallout prediction, which assumed it to be a surface burst). The maximum dose rate from fallout (outside the crater) was 3,400 R/hr, which occurred 930 feet downwind. Dose rates of 1,000, 500, 200 and 100 R/hr occurred 1,250, 3,500, 10,000, and 17,200 feet downwind at 1 hour after detonation. Anderson's Dynamic model predicts that a 1 megaton fission Nevada soil surface burst under 10 knot mean winds will produce a maximum downwind 1 hour dose rate hotspot of 6,126 R/hr at 6.9 km downwind. Doubling the windspeed reduces this hotspot dose rate by factor of 1.64 (by dispersing the same fallout over a larger area), but increases the downwind distance of the peak dose rate by factor of 1.49. Doubling the weapon yield only increases the maximum dose rate by a factor of 1.18, but increases its downwind distance by a factor of 1.34.

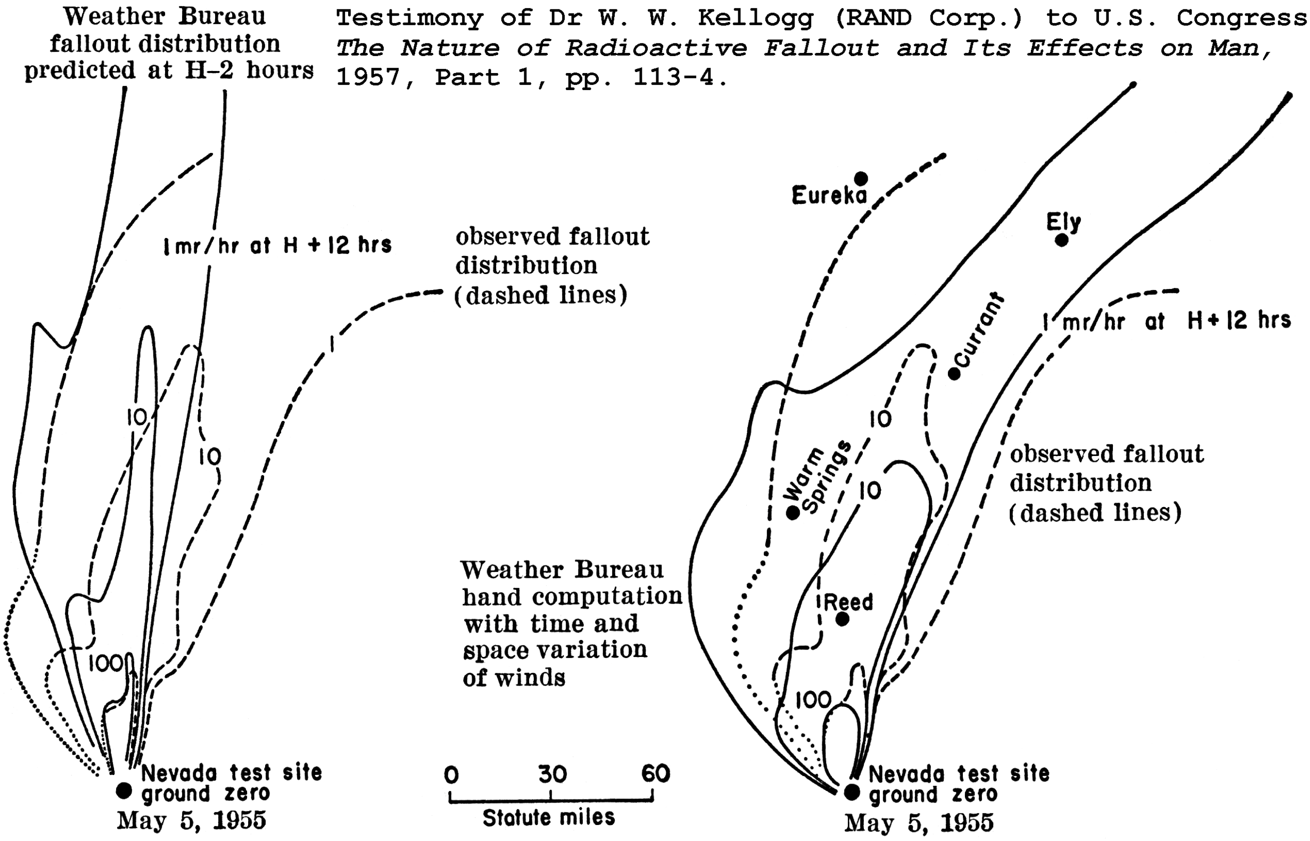


Figure 14: *Teapot-Apple 2* fallout predictions and result, 5 May 1955: Nevada Test Site, burst on the top of a 500 foot high steel tower burst, 29 kt total yield (100% fission yield). Solid lines show fallout predictions by Kenneth Nagler of the U.S. Weather Bureau, for winds forecast 2 hours before detonation (left), and for wind variations in space and time (right). Meteorologist Dr William W. Kellogg of the RAND Corporation presented the fallout patterns in his testimony to the U.S. Congressional Hearings before the 1957 Special Subcommittee on Radiation, *The Nature of Radioactive Fallout and Its Effects on Man,* pp. 104-41, where he states that Kenneth Nagler and Dr Lester Machta of the U. S. Weather Bureau found that (for 12-18 kt tests), the local fallout percentage (activity deposited within 200 miles of ground zero) was 10.8 % for the average of five 300-foot steel tower bursts, 5.4 % for a 500 foot steel tower burst (14 kt *Teapot-Apple 1*) and 1.0 % for an air burst at 524 feet (the 15 kt *Grable* test in 1953), compared to 87 % for the 1.2 kt *Jangle-Sugar* Nevada surface burst in 1951, 85 % for the 1956 *Redwing* coral surface bursts (*Zuni* and *Tewa*), and 65-70% for *Redwing* ocean surface bursts (*Flathead* and *Navajo*).

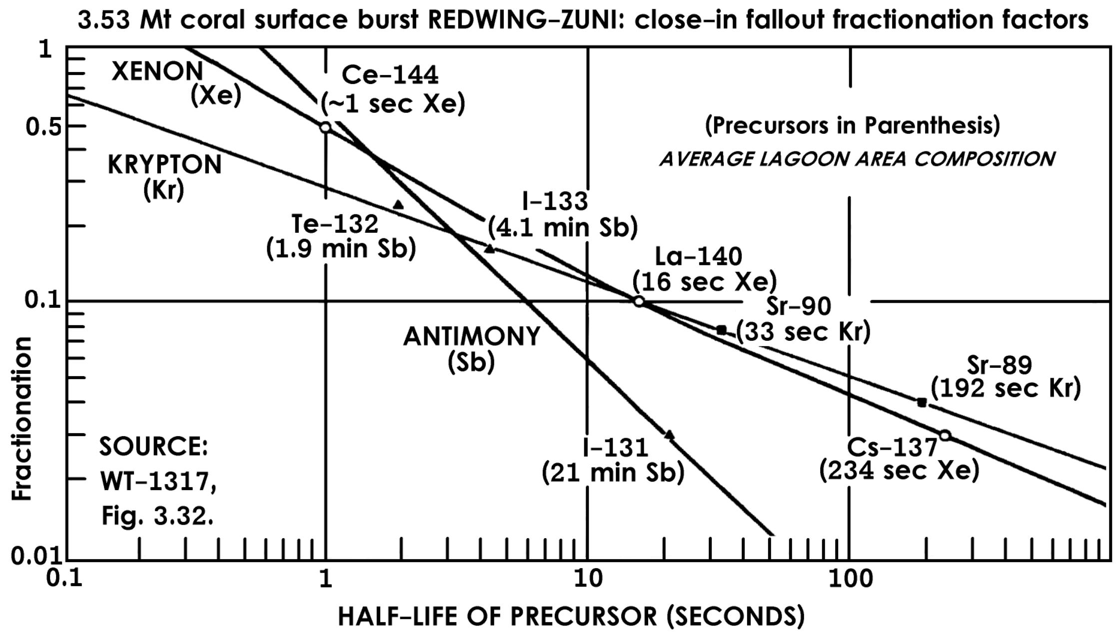


Figure 15: close-in fallout from surface bursts is *fractionated,* with greatly reduced abundances of the soluble volatile fission product like iodine-131, which can only plate the outer surfaces of fallout particles in the later stages of fireball condensation. This graph is from Terry Triffet and Philip D. LaRiviere's report *Operation Redwing, Characterization of Fallout,* WT-1317, 1961. It shows that there is a correlation between fractionation and the half-life of the volatile precursor in each decay chain.

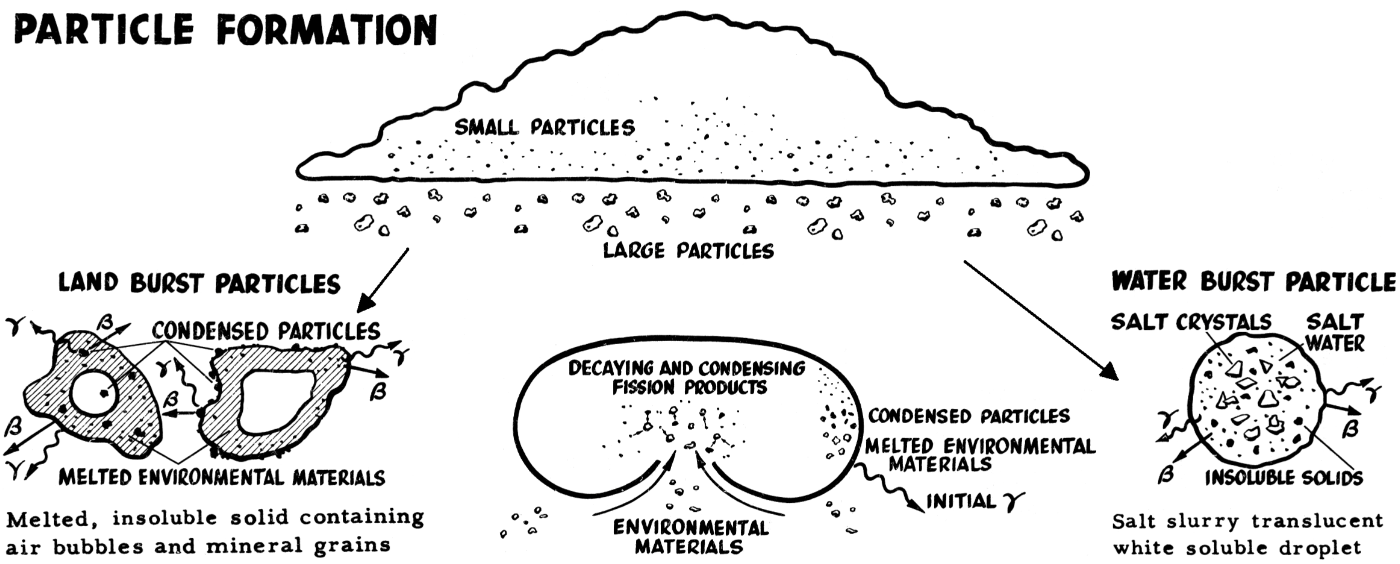
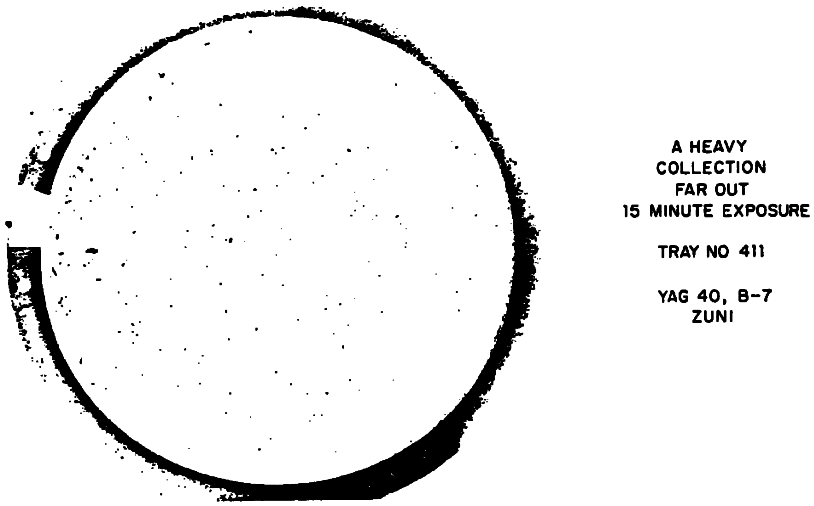


Figure 16: lethal fallout is not an invisible gas that can only be detected by special instruments. It must be carried down from high altitudes rapidly on large particles in order to produce high doses before the radioactivity decays. Only the Marshallese who saw *visible* fallout deposited from the 1954 *Castle-Bravo* 14.8 megaton coral reef surface burst 115 miles away received beta burns to bare skin, and they were burned only on moist areas of skin and coconut oil dressed hair that retained fallout for many hours. Because ordinary clothing did not retain the dry fallout particles, clothed areas were protected from beta radiation exposure. However, waterproof clothing is required for protection against wet sticky fallout particles from water surface bursts in humid air. (Illustration adapted from Dr Triffet's testimony before the Special Subcommittee on Radiation, June 1959.)



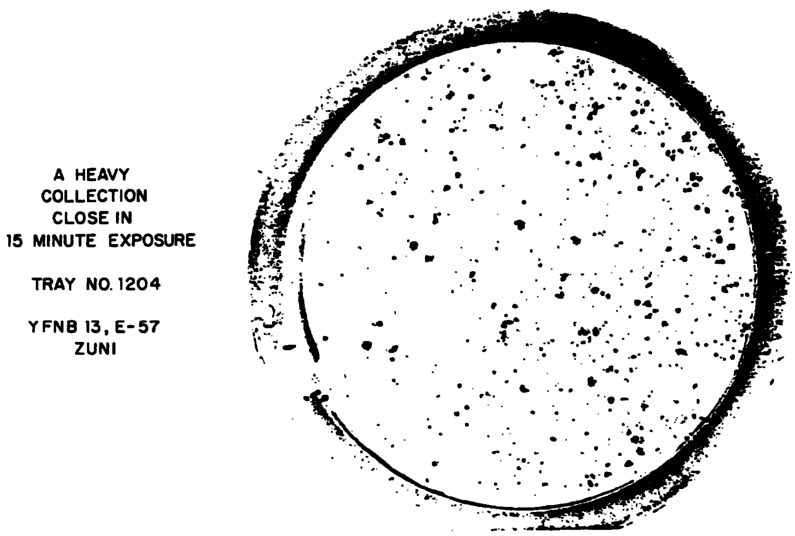


Figure 17: surface bursts loft hundreds of tons of soil/kt as fallout, so the specific activity per unit mass of fallout is relatively low, and the carrier soil makes the fallout clearly visible where there is a lethal hazard. You do not need radiation meters to determine that a lethal fallout hazard exists. These 8.1 cm-diameter trays were exposed for just 15 minutes (report WT-1317).

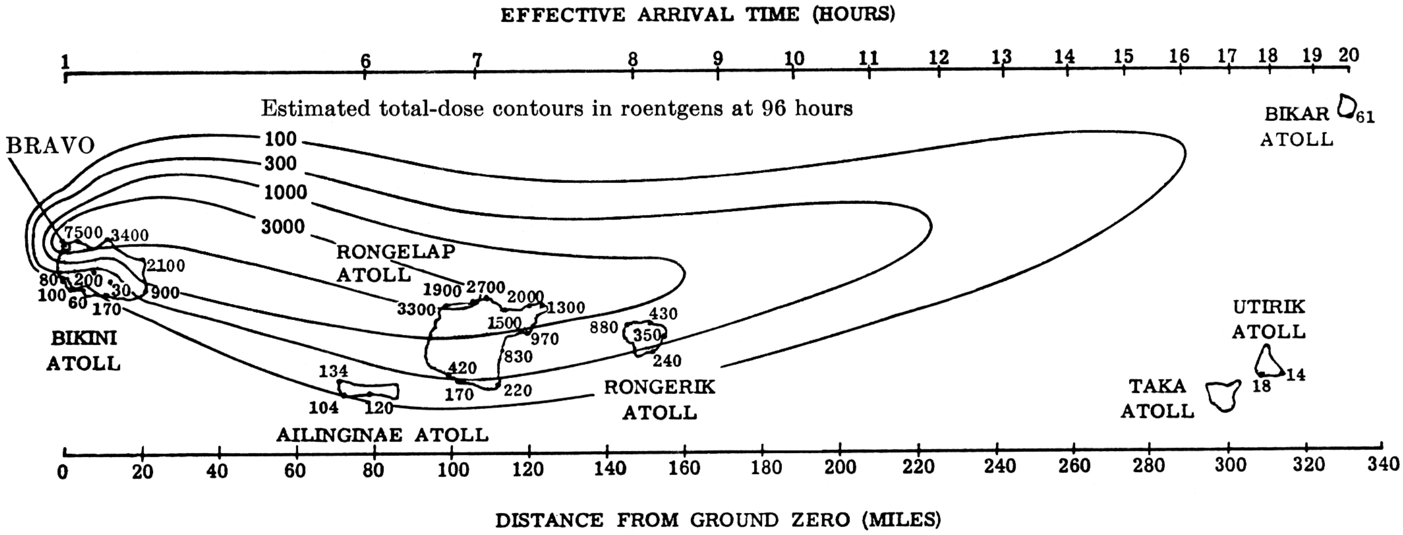


Figure 18: surface burst *Castle-Bravo* on 1 March 1954 contaminated downwind inhabited atolls (Glasstone and Dolan). Note the effective arrival time of 1 hour near ground zero: the mean fallout arrival time in the lagoon was 28 minutes, but the fallout dose rate peaked at 1 hour and material continued arriving for 2 hours, as stated in report WT-915. The fallout forecasting error was mainly due to unexpectedly high yield, since was known at before the test that Rongelap and Rongerik were downwind. *Operation Castle, Radiological Safety, Final Report,* volume II (ADA995409, 1985, pages K3-K7): "At the midnight weather briefing, the forecast offered a less favorable condition in the lower levels (10,000 to 25,000 feet). Resultant winds at about 20,000 feet were forecast in the direction of Rongelap and Rongerik; however, it was considered that the speeds and altitudes did not warrant a conclusion that significant quantities and levels of debris would be carried out so far." The March 1957 University of Utah Master of Science thesis by meteorologist Frank Cuff, *A Study of the Time Variability of Integrated Winds Near Las Vegas, Nevada,* showed that mean vector wind direction from the surface to 20,000 feet (measured by tracking the direction of weather balloon while it rises at a constant rate) varied by an average of only 12 degrees over a 3 hour period and 22 degrees over a 6 hour period, while even smaller variations occurred for the mean vector wind direction between the surface and 50,000 feet: 6 degrees over 3 hours and 13 degrees over 6 hours. The smaller average variation that occurs over the larger altitude range is due to the overall cancellation of the effects of some random shifts in wind directions by opposing changes at different altitudes: this is relevant to fallout prediction where the "hotline" or axis of maximum activity is determined by fallout concentrated at the lower portion of the mushroom cloud. Schuert states in USNRDL-TR-139, 1957: "The height lines describing the fallout from the lower portion of the mushroom immediately establish the 'hot line'."

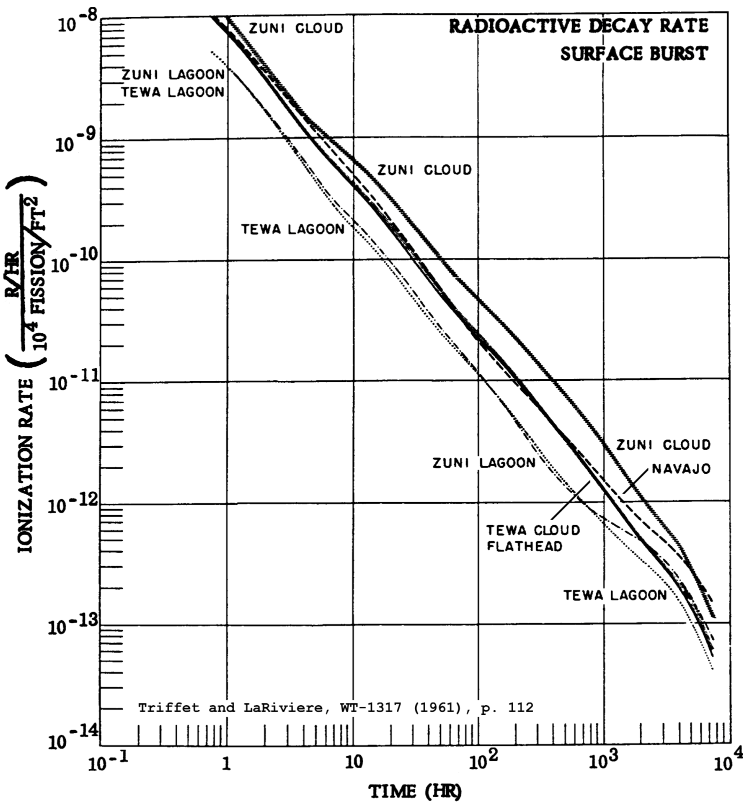


Figure 18: surface burst radioactivity decay rates depend on fractionation and neutron induced activities such as Np-239 and U-237 produced by neutron capture reactions with U-238 in the bomb. But *Zuni* (3.53 Mt 15% fission coral island surface burst), *Tewa* (5.01 Mt 87% fission coral reef surface burst), *Flathead* (365 kt 73% fission ocean surface burst) and *Navajo* (clean 4.5 Mt 5% fission ocean surface burst) led to a fractionated (lagoon) and unfractionated (cloud) fallout decay ~(time)$^{-1.2}$.

Measured capture to fission ratios in nuclear tests*

Test shot	*Weapon design*	*Yield*	*Fission %*	*Number of neutron capture atoms per fission* U-239 & Np-239	*U-237*	*U-240 & Np-240*
Jangle-Sugar	U238 reflector	1.2 kt	100	0.59		
Jangle-Uncle	U238 reflector	1.2 kt	100	0.59		
Castle-Bravo	U238 pusher	14.8 Mt	68	0.56	0.10	0.14
Castle-Romeo	U238 pusher	11 Mt	64	0.66	0.10	0.23
Castle-Koon	U238 pusher	110 kt	91	0.72	0.10	
Castle-Union	U238 pusher	6.9 Mt	72	0.44	0.20	0.07
Redwing-Zuni		3.53 Mt	15	0.31	0.20	0.005
Redwing-Tewa		5.01 Mt	87	0.36	0.20	0.09
Diablo	U238 in core**	18 kt	100	0.10		
Shasta	U238 in core**	16 kt	100	0.10		
Coulomb C	U238 in core**	0.6 kt	100	0.03		

* Data is derived from all analyses of aircraft cloud fallout samples and deposited fallout samples in Dr Carl F. Miller, U.S. Naval Radiological Defense Laboratory, report USNRDL-466 (1961), Table 6.
**In these Plumbbob weapon tests, there was no U238 reflector and the only U238 in the bomb was that contained in the fissile core as an impurity.

Measured relationship between the fusion yield of the nuclear explosive and the quantity of neutron-induced activities in the fallout*

Test		*Redwing-Navajo*	*Redwing-Zuni*	*Redwing-Tewa*	
Design		Lead pusher	Lead pusher	U-238 pusher	
Total yield		4.5 Mt	3.53 Mt	5.01 Mt	
% Fission		5	15	87	
% Fusion		95	85	13	
Nuclide	Half life	Abundance of nuclide in bomb fallout, atoms per bomb fission			*R1***
Na-24	15 hours	0.0314	0.0109	0.00284	1284.7
Cr-51	27.2 days	0.0120	0.0017	0.00030	0.280
Mn-54	304 days	0.10	0.011	0.00053	0.614
Mn-56	2.58 hours	0.094		0.00053	2668
Fe-59	45.2 days	0.0033	0.00041	0.00017	6.19
Co-57	272 days	0.00224	0.0031	0.00018	0.113
Co-58	71 days	0.00193	0.0036	0.00029	3.11
Co-60	5.27 years	0.0087	0.00264	0.00081	0.299
Cu-64	12.8 hours	0.0278	0.0090	0.0023	89.5
Sb-122	2.75 days		0.219***		38.4
Sb-124	60 days		0.073***		6.92
Ta-180	8.15 hours	0.038	0.0411		35.9
Ta-182	114 days	0.038	0.0326	0.01	2.67
Pb-203	52 hours	0.0993	0.050	0.000018	26.0
U-237	6.75 days		0.20	0.20	6.50
U-239	23.5 minutes	0.085	0.31	0.36	173
Np-239	56.4 hours	0.085	0.31	0.36	14.9*+*
U-240	14.1 hours		0.005	0.09	0 (no gamma rays)
Np-240	7.3 minutes		0.005	0.09	150

*Dr Terry Triffet and Philip D. LaRiviere, "Characterization of Fallout, Operation Redwing, Project 2.63," U.S. Naval Radiological Defense Laboratory, 1961, report WT-1317, Table B.22. Data on U-238 capture nuclides is from USNRDL-466, Table 6, in combination with WT-1315, Table 4.1.
**Triffet's 1961 values for the gamma dose rate at 1 hour after burst at 3 ft above an infinite, smooth, uniformly contaminated plane, using an ideal measuring instrument with no shielding from the person holding the instrument, from 1 atom/fission of induced activity, (R/hr)/(fission kt/square stat mile).
***The Zuni bomb contained a lot of antimony (Sb), which melts at 903.7K and boils at 1650K. The abundances of Sb-122 and Sb-124 given in the table are for unfractionated cloud samples; because of the low boiling point of antimony, it was fractionated in close-in fallout, so the abundances of both Sb-122 and Sb-124 in the Zuni fallout at Bikini Lagoon were 8.7 times lower than the unfractionated cloud fallout.
*+*Note that Np-239 at 1 hour after burst is still forming as the decay product of U-239.

Figure 19: The *low energy of gamma rays from Np-239 and U-237 in the first couple of weeks makes it easier to shield gamma from U-238 cased "dirty" weapons*. The original anti-civil defense propaganda on fallout in the 1950s and 1960s originated from false claims about neutron induced activity affecting the decay rate of the fallout substantially for salted or cobalt-60 weapons, e.g. Shute's novel *On the Beach* and the Kubrick film *Dr Strangelove*. But for each neutron used for the fission of U-238 you get 200 MeV of energy, *including far more residual radioactivity energy than from capturing the neutron in cobalt-59 to produce cobalt-60*. The smaller dose of gamma ray energy from the cobalt-60 *gets spread over a longer period of time, producing smaller dose rates, enabling decontamination to wash the fallout away before a high dose is accumulated.*

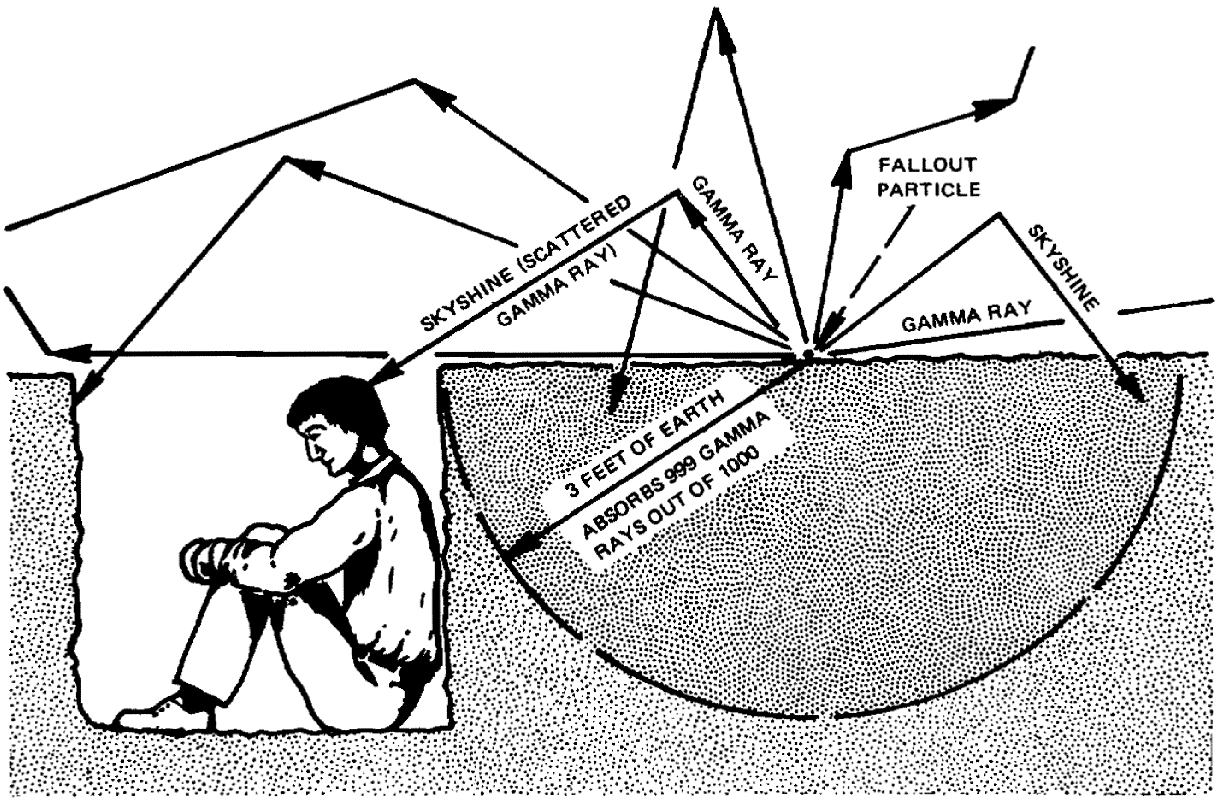


Figure 20: At 1 metre height above a uniformly contaminated smooth, unobstructed surface, 90% of the gamma dose rate is from direct gamma rays and 10% is from air scatter. Some 50% of this gamma radiation dose is contributed by the fallout deposited beyond a radius of 15 metres, so the average angle of the gamma rays contributing most of the dose is almost horizontal. The air scattered gamma rays have a wide distribution of angles, and are not all coming down vertically, so some of them are also absorbed. This is why typically 90% (i.e. the direct gamma ray dose) is stopped in any below ground depression such as a narrow ditch or trench. The fallout directly under your feet contributes a negligible proportion to your dose, owing to the long range of gamma rays in air. Fallout directly under your feet contributes an insignificant percentage of the dose. Even if there is fallout blown into a house through blast shattered windows, the walls will continue to shield the major portion of the radiation dose, which is from the direct gamma rays from a wide area outdoors (Kearny, ORNL-5037).

Spectrum of fission product gamma rays from the thermonuclear neutron fission of U-238 (Glenn R. Crocker, *Radiation Properties of Fractionated Fallout; Predictions of Activities, Exposure Rates and Gamma Spectra for Selected Situations,* U.S. Naval Radiological Defense Laboratory, USNRDL-TR-68-134, 27 June 1968, 287 pp.)

Gamma ray energy, MeV	Fission product gamma spectrum at 1 hour				Fission product gamma spectrum at 1 week			
	Sr-89 abundance (relative to unfractionated fallout)				Sr-89 abundance (relative to unfractionated fallout)			
	10% $R_{89,95} = 0.1$	50% $R_{89,95} = 0.5$	100% $R_{89,95} = 1$*	200% $R_{89,95} = 2$	10% $R_{89,95} = 0.1$	50% $R_{89,95} = 0.5$	100% $R_{89,95} = 1$*	200% $R_{89,95} = 2$
0-0.5	0.396	0.354	0.350	0.304	0.695	0.662	0.678	0.637
0.5-1	0.385	0.379	0.363	0.357	0.262	0.270	0.245	0.265
1-1.5	0.1605	0.1863	0.1914	0.232	0.01339	0.01358	0.01218	0.01273
1.5-2	0.0327	0.0466	0.0558	0.0596	0.0287	0.0519	0.0591	0.0790
2-2.5	0.01628	0.0203	0.0279	0.0290	0.001114	0.001313	0.001268	0.001445
2.5-3	0.00429	0.00717	0.01192	0.01305	0.001372	0.00253	0.00291	0.00388
3-3.5	0.00340	0.00301	0.00267	0.00273	0.0000260	0.0000490	0.0000564	0.0000760
3.5-4	0.001425	0.001187	0.001705	0.00214	0	0	0	0
Total:	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Relative gamma activity	0.547	0.756	1	1.25	0.563	0.768	1	1.12
Mean energy, MeV	0.710	0.767	0.807	0.856	0.444	0.486	0.483	0.526

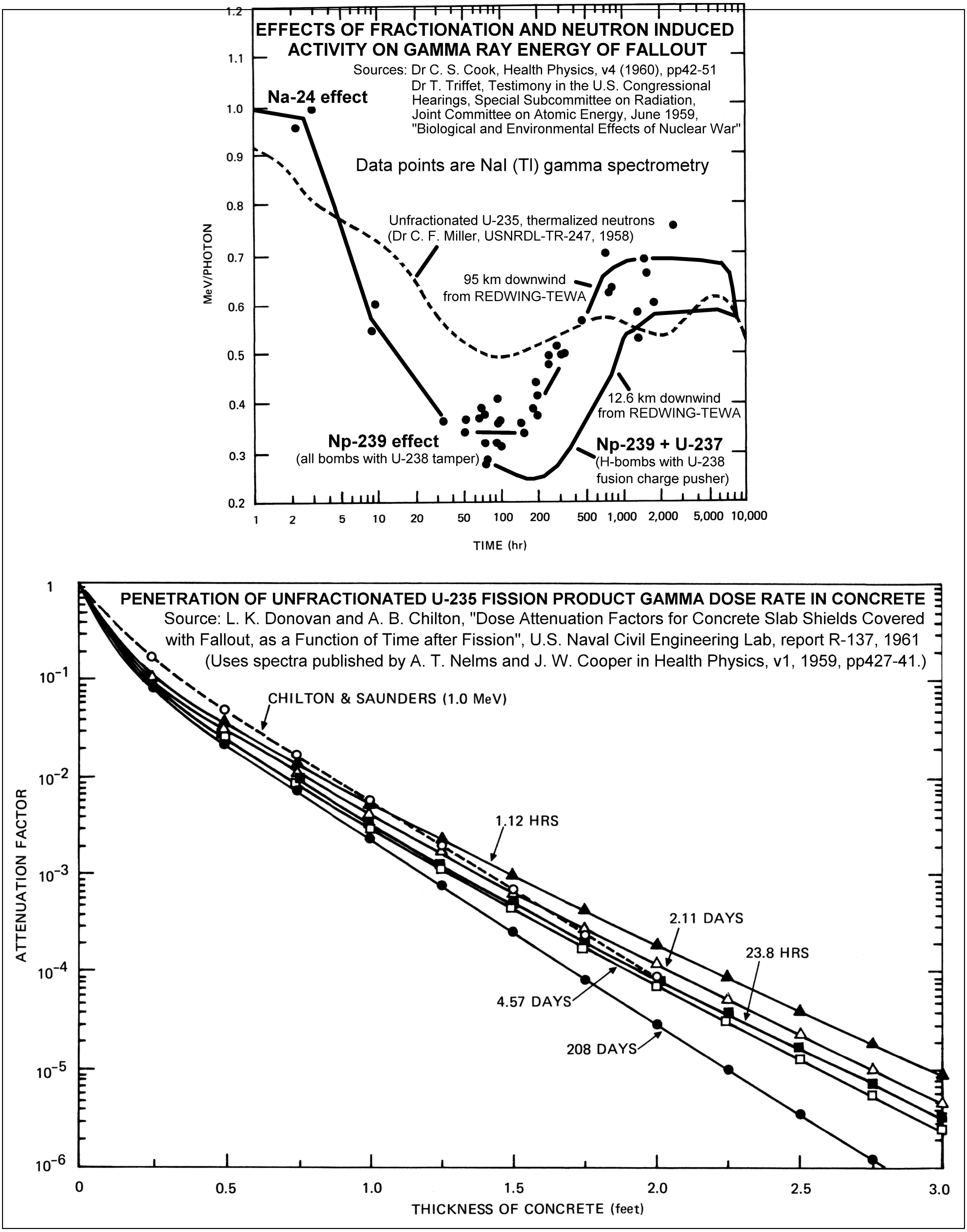


Figure 21: fallout radiation protection factor calculations are traditionally made assuming the 1.25 MeV mean gamma ray energy of cobalt-60, not the wider spectrum of actual gamma rays from bomb fallout. This leads to substantial underestimates of protection factors which are smaller than 100. The effect of Np-239 and U-237 (which make a maximum percentage contribution to $t^{-1.2}$ fallout decay radiation at a time of 1.2/ln2 = 1.73 times their respective half-lives of 56 hours and 6.8 days, i.e. 97 hours and 12 days, respectively) further softens the gamma ray spectrum, increasing the benefits of any shielding, as explained by *Operation Redwing* fallout characterization project officer Dr Terry Triffet to congress in June 1959.

Dr Triffet at the 22-26 June 1959 Congressional Hearings on the *Biological and Environmental Effects of Nuclear War* pages 61-111 showed that at 1 week after burst, the mean gamma ray energy of fractionated fallout 8 statute miles downwind of a megaton range surface burst was 0.25 MeV, while at 60 statute miles downwind it was 0.35 MeV (due to less depletion of high energy fission products at greater distances, a fractionation effect). On page 205 of the June 1959 hearings on the *Biological and Environmental Effects of Nuclear War,* Dr Triffet explained that the low gamma ray energy makes most of the radiation very easy to shield by improvised emergency countermeasures:

"I thought this might be an appropriate place to comment on the variation of the average energy. It is clear when you think of shielding, because the effectiveness of shielding depends directly on the average energy radiation from the deposited material. As I mentioned, Dr Cook at our [U.S. Naval Radiological Defense] laboratory has done quite a bit of work on this. ... if induced products are important in the bomb [i.e. in high fission devices employing U-238 ablative "pushers" or fusion capsule jackets], there are a lot of radiations emanating from these, but the energy is low so it operates to reduce the average energy in this period and shielding is immensely more effective."

There is extensive data on the gamma ray spectrum of fallout from the *Zuni, Tewa, Flathead* and *Navajo* surface bursts in Table B.21 of Triffet and LaRiviere's 1961 report *Characterization of Fallout* (WT-1317) and in Tables 1 and 2 of W. E. Thompson's report *Spectrometric Analysis of Gamma Radiation from Fallout from Operation Redwing* (U. S. Naval Radiological Defense Laboratory technical report USNRDL-TR-146, 1957). For example, Thompson gives the detailed spectrum of gamma radiation measured on Bikini Island (codenamed How Island, fallout collector F-61, sample GA) at 13 miles east-north-east of ground zero for the 3.53 Mt 15% fission coral surface burst *Zuni*. At 10 days after this detonation, the mean gamma ray energy emitted by this sample was just 0.218 MeV. Since shielding thicknesses are roughly proportional to the square root of the gamma ray energy, shielding thicknesses needed for a given protection factor at this time were 2.4 times smaller than for cobalt-60 gamma radiation (1.25 MeV mean).

Zuni* fallout gamma ray spectrum measured at 10 days after detonation, 13 miles downwind (sample How F-61 GA)

Gamma ray energy (MeV)	% of gamma rays emitted by fallout sample
0.060	15.5
0.105	38.8
0.220	19.4
0.280	9.3
0.330	3.8
0.500	3.9
0.650	3.1
0.750	6.2
Mean energy	**0.218 MeV**

*W. E. Thompson, *Spectrometric Analysis of Gamma Radiation from Fallout from Operation Redwing,* U. S. Naval Radiological Defense Laboratory technical report USNRDL-TR-146, 29 April 1957, Tables 1 and 2. Note that this is the gamma ray spectrum actually measured for a fallout sample placed near the scintillation crystal of a gamma ray spectrometer, so it does not include the further reduction in gamma ray energy that occurs from Compton scattering in the atmosphere.

Ocean water surface burst fallout is unfractionated so it emits slightly higher energy gamma rays. For example, R. L. Stetson's report *Operation Castle, Project 2.5a, Distribution and Intensity of Fallout,* WT-915, 1956, on page 145 states that the measured mean gamma ray energy of a fallout sample from the 13.5 Mt 52% fission *Castle-Yankee* ocean surface burst was 0.344 MeV at 8 days after detonation. Nevertheless, this is still substantially less than the 1.25 MeV mean energy of the cobalt-60 gamma rays assumed in most protection factor calculations, and is only about half of the 0.7 MeV figure mentioned by Glasstone. (The *Castle-Yankee* U-238 neutron capture nuclide abundances are similar to those for *Castle-Romeo* in Figure 19 above.)

Further reading on the effects of nuclear weapons

Bridgman, Charles J., *Introduction to the Physics of Nuclear Weapons Effects,* DTRA, 2001.
Dolan, Philip J., *Capabilities of Nuclear Weapons,* DNA-EM-1, 2 volumes, 1972, change 1 (1978), change 2 (1981).
Glasstone, Samuel, and Philip J. Dolan, *Effects of Nuclear Weapons,* 3rd ed., 1977.
Northrop, John A., *Handbook of Nuclear Weapon Effects: Calculational Tools Abstracted from DSWA's Effects Manual One (EM-1),* Defense Special Weapons Agency, 1996.
Military Research and Development Subcommittee, Committee on Armed Services, *Electromagnetic Pulse Threats to U. S. Military and Civilian Infrastructure,* Published record of Congressional Hearings held on 7 October 1999.
Special Subcommittee on Radiation, Joint Committee on Atomic Energy, *Biological and Environmental Effects of Nuclear War,* Published record of Congressional Hearings held from 22-26 June 1959.
Special Subcommittee on Radiation, Joint Committee on Atomic Energy, *Nature of Radioactive Fallout and Its Effects on Man,* Published record of Congressional Hearings held from May-June 1957.